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NERVA NOZZLE DESIGN STATUS REPORT

PROJECT 141

MAY 1972

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CLASSIFICATION CATEGORY

Unclassified

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I. INTRODUCTION

The purpose of this document is to report on the results of design analyses and to depict the status of the attained design maturity of the structural elements of the nozzle jacket and various aspects of the coolant passages.

I contrast with the work previously accomplished (whereby the design feasibility using very conservative design allowables of ARMCO 22-13-5 has been established), these design analyses related to the nozzle shell were based on more realistic design allowables as supported by cursory values obtained from ARMCO 22-13-5 nozzle forgings.

In regards to the CRES 347 coolant passages the major aspects under consideration were:

1. Low cycle thermal fatigue
2. Ability to operate at 4500°R gas temperature
3. Tube buckling
4. Susceptibility to erosion

The design maturity attained of these, and other more conventional failure mechanisms, is displayed in the following section via Reliability Summary Table.

The scope of analyses contained in this document is limited to processes leading to reliability assessments of failure mechanisms within Failure Modes Analyses Section VII (Containment and Delivery of the Coolant Flow) and Section VIII (Containment of the Hot Gas).

II. SUMMARY AND CONCLUSIONS

A. SUMMARY

1. Structural and Reliability Analyses of the Nozzle Jacket and the Nozzle/Pressure Vessel Joint

The basis used for both the structural and reliability analyses were ARMCO 22-13-5 material properties shown in Figure 1. Assuming that the statistically arrived at design values will support the reflected cursory data, with one exception all elements of the nozzle reinforcing jacket, nozzle to pressure vessel mating flange and all manifolds made from ARMCO 22-13-5 will meet or exceed the reliability requirements.

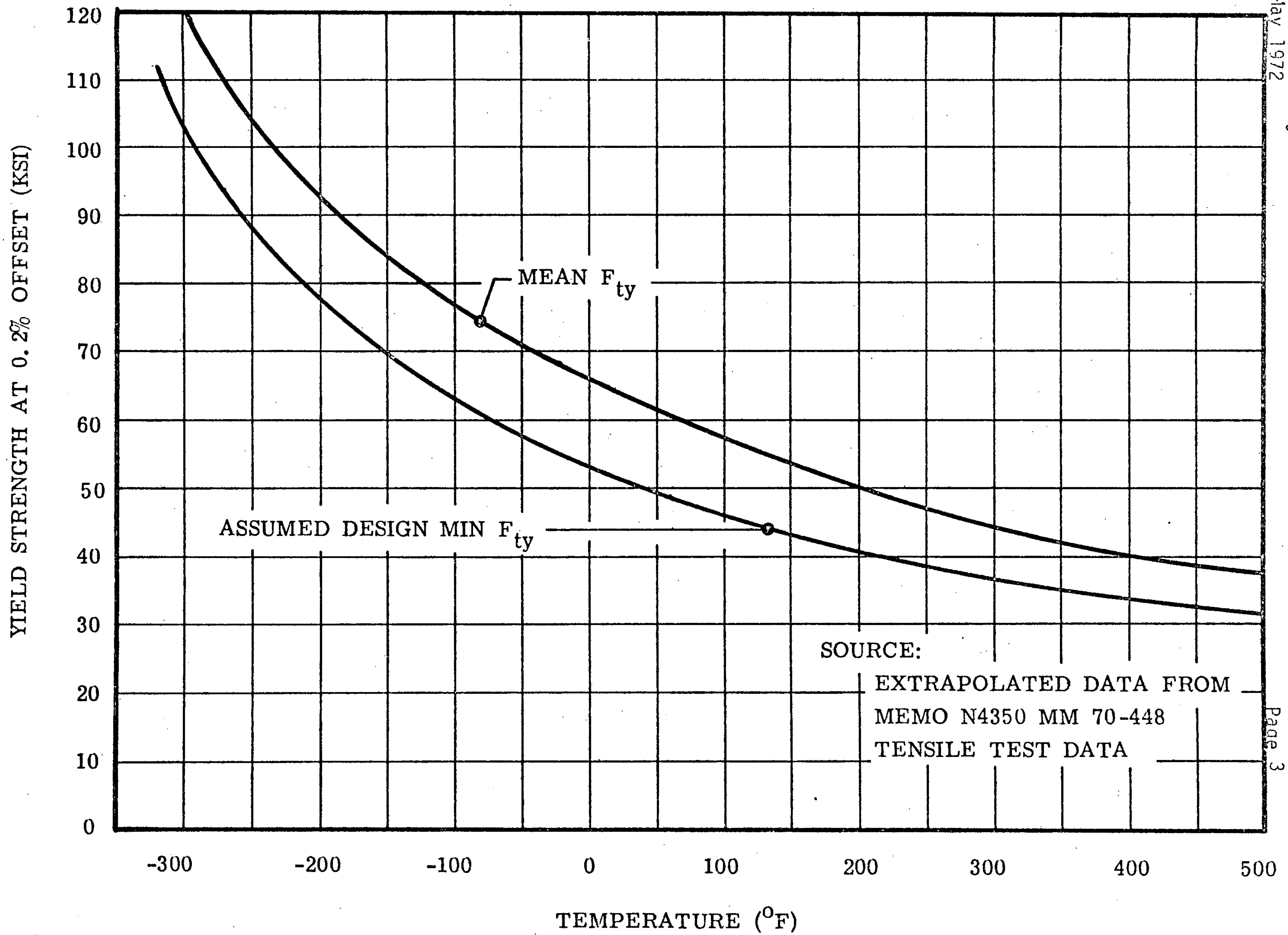
The one exception noted is the barrel portion of the core support where it would appear that a thickness greater than 0.6 in. may be required.

By the same token, it appears that the very high reliability in the nozzle flange (lands between bolt holes and shear lip) permits a reduction of the flange thickness.

It is expected that some vernier design adjustment will be required upon availability of statistical data. However, the generally very satisfactory design status, as reflected in Table I, does not warrant a design modification at this time.

The more realistic design values used in the analyses result in 300 lb. weight reduction of the nozzle. Such reduction permits the construction within the allocated weight of 1650 lbs.

ARMCO 22-13-5 YIELD STRENGTH



L. A. Shurley
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FIGURE 1

TABLE I

RELIABILITY SUMMARY
FINAL 75K NERVA NOZZLE RELIABILITY CALCULATIONS
ARMCO 22-13-5, 2.0 INCH FLANGE: CRES 347 TUBES

FMA VII	COOLANT PASSAGES	MARGIN OF SAFETY	CALCULATED RELIABILITY	RELIABILITY ALLOCATION	FAILURE CATEGORY
A.	Inlet Manifold	.186	$.9_{16}47$	$.9_{10}88$	IV
B.	Inlet Elbow	2.97	$.9_{18}88$	$.9_{10}88$	IV
C.	Elbow Weld	.82	$.9_{15}89$	$.9_{10}88$	IV
D.	Tube Erosion	.26	$.9_{9}67$	$.9_{6}89$	III
E.	Tube Rupture	.26	$.9_{11}58$	$.9_{10}88$	IV
F.	Tube Buckling	.16	$.9_{7}8$	$.9_{6}89$	III
G.	Tube Fatigue		$.9_{8}8$	$.9_{6}89$	III
H.	Coolant Manifold	9.2	$.9_{23}$	$.9_{10}88$	IV
I.	End Cap	3.0	$.9_{17}9$	$.9_{10}88$	IV
J.	End Cap Braze (to tube)		$.9_{10}88$*	$.9_{10}88$	IV
K.	End Cap Weld (to jacket)		$.9_{11}$	$.9_{10}88$	IV
L.	Bolt Seal Leak	Calculations not complete			
M.	Jacket Rupture (Aft End)	1.46	$.9_{17}8$	$.9_{10}88$	IV
N.	Tube Braze Joints		$.9_{10}88$**	$.9_{10}88$	IV
O.	Inlet Manifold Weld	.80	$.9_{15}71$	$.9_{10}88$	IV
P.	Nozzle/P.V. Seal Leak	Calculations not complete			
Q.	Bolt Coolant Manifold Weld	3.08	$.9_{23}$	$.9_{10}88$	IV

FMA VIII	NOZZLE FORMS AFT CLOSURE FOR P.V. AND SUPPORTS CORE	MARGIN OF SAFETY	CALCULATED RELIABILITY	RELIABILITY ALLOCATION	FAILURE CATEGORY
A.	Lands between Bolt Holes	.80	$.9_{20}$	$.9_{10}8$	IV
B.	Shear Lip	.58	$.9_{17}$	$.9_{10}$	IV
C.	Nozzle P.V. Bolts***				
	Leakage (Flange Separation)	-	$.9_{7}6$	$.9_{7}$	III
	Structural	.01	$.9_{11}5$	$.9_{10}8$	IV
D.	Jacket Membrane (Hoop Stress)	.36	$.9_{11}5$	$.9_{10}8$	IV
	(Meridional)	.56	$.9_{18}4$	$.9_{10}8$	IV
E.	Core Support	.37	$.9_{8}63$	$.9_{10}8$	IV

*Assumes 30% engagement.

**Assumes 20% engagement.

***Nozzle P/PV bolt calculations cover one bolt only. Effect of bolt coolant channel blockage, kiinsert failure, and the effect of 2 adjacent bolts or kiinserts failing was not calculated at the time of publication of this document.

2. Structural and Reliability Analyses of the Coolant Passage

The degree of completeness of analytical work accomplished is reflected in Table 1. The Table reveals that at the time of termination of the NERVA Engine Program only the performance with respect to leakage of the "K" seal under the bolt heads and the "Omega" seal outside of the bolt circle remain unanalyzed. All other aspects of the coolant passage were analyzed and with respect to all other failure mechanisms the entire coolant passage system was found to have met or exceeded the reliability requirements.

a. Coolant Channel Attachment to the Nozzle Shell

Although Table I, Item VII N shows that the allocated reliability of braze joint between the coolant channels and the jacket can be met with as little as 20% engagement---this assumes that a suitable positive inspection method of channels' insertion into jacket grooves would be implemented. To eliminate the dependency on the validity and thoroughness of inspection, an alternate means of coolant channel insertion and attachment has been conceived. The necessity of spot welding and monitoring the depth of channels' insertion has been eliminated and mechanical lock is proposed instead.

The new method is described in detail in the "Discussion" Section III.

b. Coolant Channel Low Cycle Thermal Fatigue

Within the constraints of available data, the previous assumption that under "Hold Conditions" 30% degradation in "No-Hold" cycling life can be expected was overly pessimistic---though acceptable from reliability point of view.

Data indicates that no degradation will be experienced with CRES 347 Coolant Channels and that the required reliability for this mechanism of $.9_6 9$ can easily be met. Although 25% increase in strain will take place at wall temperature of 1600°F as the result of 4500°R gas temperature, no change in cycling life with respect to a lower strain with 1400°F wall temperature at 4250°R plenum temperature is expected.

c. Coolant Channel Erosion

A high reliability, considerably in excess of allocated requirement, for this failure mechanism was obtained.

Consideration was given to absence of oxidizing or carburizing atmosphere. Incipient (lower limit) erosion was postulated to take place at 1950°F with 2025°F temperature representing a mean. Within this assumption, operation at 4500°R and resulting coolant channel wall temperature at maximum heat flux point erosion is considered as not credible mechanism of failure. The target reliability can be met even if the mean and incipient erosion temperatures were 2000°F and 1850°F respectively.

d. Coolant Channel Buckling

Using NAR experimental data and assuming 300°R uncertainty in the reactor exit gas temperatures of 4250°R and 4500°R respectively, the allocated reliability can be met.

The items referred to above were called to the reader's attention because they were subject to more complex considerations and in the past certain difficulties were encountered in meeting the reliability goals.

Improvements in methodology or elimination of certain unduly conservative assumptions from analytical processes resulted in meeting the reliability targets. For detailed analyses related to these and other more conventional failure mechanisms listed in Table I, the reader is referred to appropriate appendices.

B. CONCLUSIONS

1. Using the design values of ARMCO 22-13-5 as shown in Figure 1, the nozzle shell can be constructed within the allocated weight of 1650 lbs, and the allocated reliability can be met.

2. Reliability targets for all failure mechanisms of the coolant passages can be met.

3. Operating the nozzle at 4500°R gas temperature at 75,000 lb thrust level (442 psia P_c) does not induce limitations with respect to cycling life, duration or susceptibility to erosion and buckling.

4. It has been demonstrated analytically that within the analyses performed no credible failure modes and mechanisms exist and therefore with no structural failures, no external or internal loss of propellant, the nozzle performance requirement with respect to thrust and specific impulse will also be met.

III. TECHNICAL DISCUSSION

A. BACKGROUND

1. ARMCO 22-13-5 Nozzle Shell

The analytical work (thermal, stress and reliability analyses) conducted heretofore was of preliminary nature with a primary objective to demonstrate the design feasibility. Such work was based on very conservative assumptions regarding the design allowables. In addition, in order to satisfy the Margin of

Safety as defined in SNSO-C-1, it was imperative to perform all related thermal and stress analyses based on specification extreme values of design and operational parameters. While this approach is consistent with SNSO-C-1, with respect to the Margins of Safety, it is not consistent with procedures governing the determination of reliability where the mean values of strength/stress relationship and their variances are involved. Nevertheless, in order to assess the magnitude of various design problems, with thermal and stress analyses for mean operating conditions not available at the time, reliability calculations were based on specification extreme values. Thus not surprizingly, while it was demonstrated that the desired reliability level was attainable in most cases, the excessive conservatism reflected in the assumed material allowables and in the procedures used resulted in an excess weight penalty of approximately 350 lbs.

The subsequent sections of this report address themselves to design refinements based on the latest material properties available and a more realistic design approach.

2. CRES 347 Coolant Channels

In the past design inadequacies or analytical deficiencies in several failure mechanisms of the coolant channels were found to exist. Some of the deficiencies reflected the lack of data while others required only some refinements in analytical processes. These items which required refinements or updating of the design maturity are identified below.

a. Coolant Channel Attachment to the Nozzle Shell

A need for an improved and more positive means of attachment of the CRES 347 "U" shaped coolant channels in the grooves of the ARMCO shell became apparent during the brazeability study of the two materials. A proposed alternate method is given further in the text.

b. Coolant Channel Low Thermal Fatigue

Previous analyses based on purely cycling but "no-hold" data, necessitated certain assumptions related to hold effect. Cursory data under 10 minutes hold conditions at few selected points of interest eliminates such previous assumptions. An updated status on the fatigue phenomenon of the CRES 347 material is enclosed.

c. Coolant Channel Erosion

An erroneous approach to assessment of susceptibility to erosion of the coolant channels under NERVA operating conditions led to a disturbingly low reliability of $.7_{xx}$. A new rational with a revised calculated reliability is provided.

d. Coolant Channel Buckling

The possibility of coolant channel buckling in cylindrical section of the nozzle has been previously recognized.

A solution designed to preclude such possibility, backed up by experimental data generated for this purpose, has been disclosed on previous occasions and is reflected in various drawings within this report. The aspects of reliability herein recorded has not been documented before.

The contents of the subsequent sections provide information on how the reliability requirements as listed in the Summary (Table I) have been attained.

B. DESIGN DESCRIPTION

ANSC nozzle master layout 1138000D depicts nozzle design subject to all analyses contained in this document.

No changes were made in the basic concept consisting of a flat face nozzle to pressure vessel joint, ARMCO 22-13-5 nozzle jacket material, CRES 347 coolant channels brazed to the nozzle jacket after preplacing and attaching the "U"-shaped channels by the splot welding technique. However, there were refinements made to the structural members of the assembly as described below.

1. Nozzle Jacket and Pressure Vessel Mating Flange

a. Cylindrical (Barrel) Section of the Nozzle

No changes were made to the barrel section. 0.6 inch thickness was retained. It is conceivable that statistical material properties will justify retention of this thickness. Should this not be the case, a minor adjustment probably not exceeding 0.050 inch addition or reduction of the thickness may be required. The design shown represents an optimum within $\pm$ 10%.

The reader will find additional dissertion on this subject in the Reliability Section.

b. Pressure Vessel Mating Flange

A flat face---surface plane interfacing with the pressure vessel normal to the nozzle axis---has been retained because it constitutes the only arrangement which provides accessibility through the bolt holes for mechanical attachment to the nuclear subsystem.

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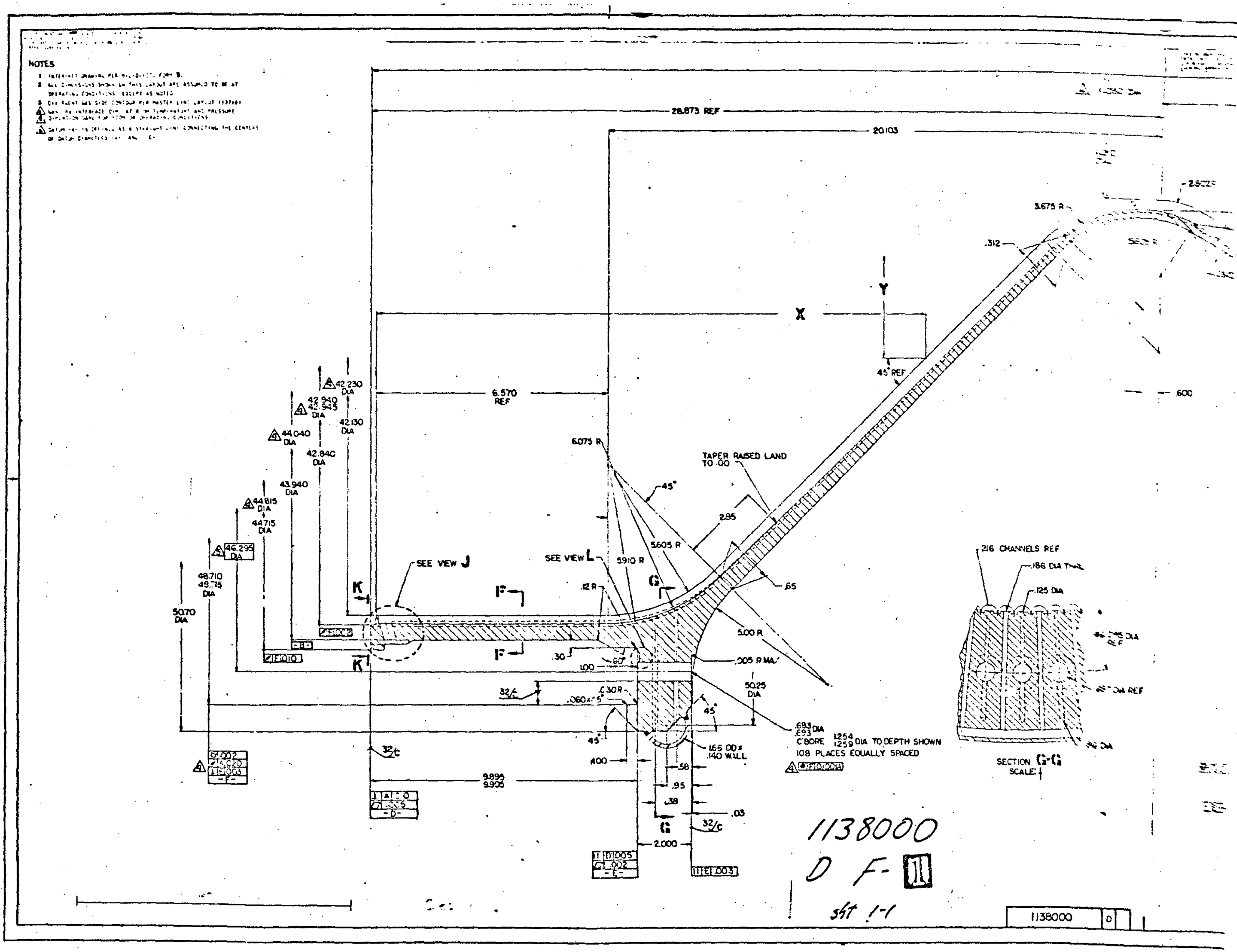

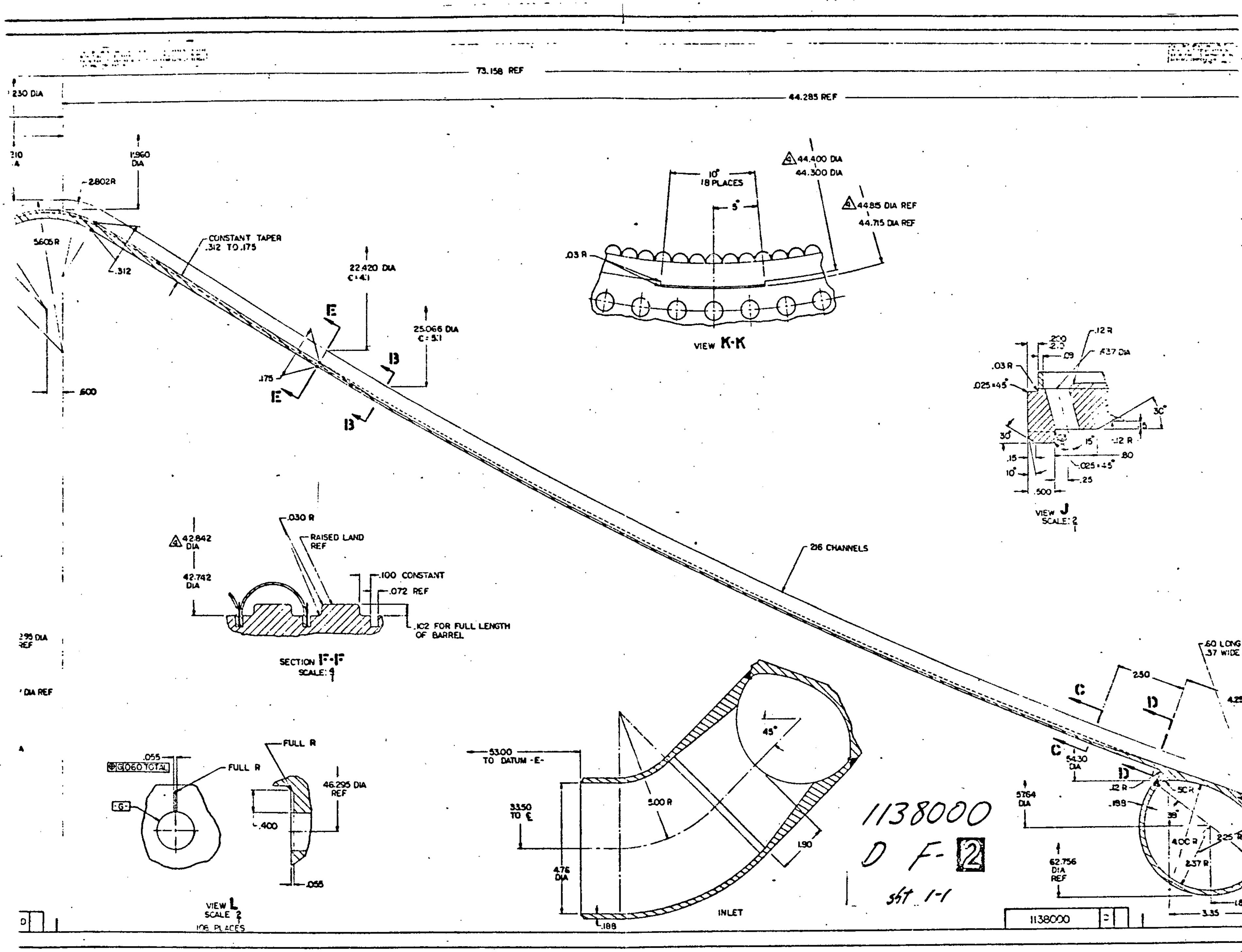

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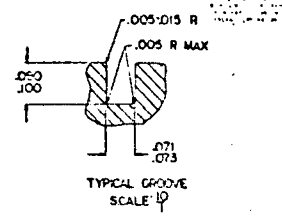
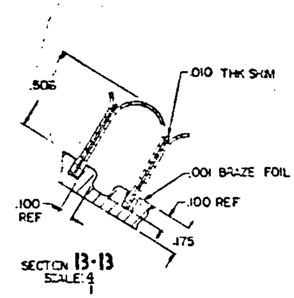
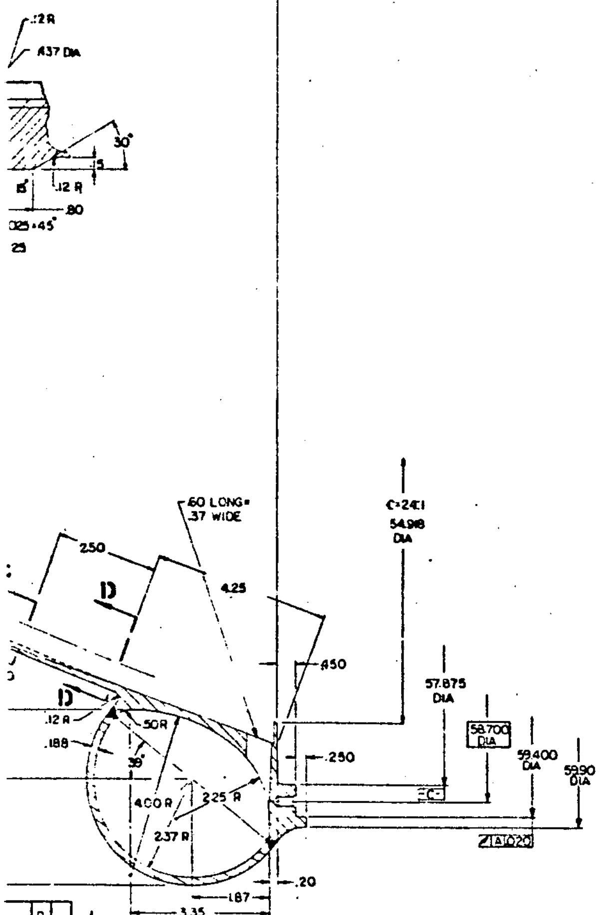
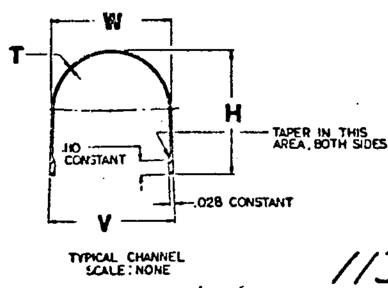
B

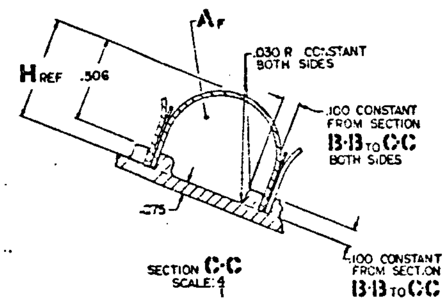


C	X_{DIM}	Y_{RAD}	W $^{+.000}_{-.004}$	V $^{+.000}_{-.004}$	H ±.005	T ±.001	A_F
24	72.959	27.459	.800	.805	.606	.029	.296
22	69.823	26.240	.765	.771		.028	.285
20	66.673	25.062	.729	.736		.028	.320
18	63.495	23.720	.691	.698		.029	.304
16	60.268	22.410	.651	.658		.027	.289
14	56.931	20.972	.608	.616		.026	.270
12	53.648	19.476	.562	.571		.025	.250
10	50.193	17.725	.512	.521		.024	.228
8	46.563	15.853	.457	.467		.023	.202
7	44.673	14.919	.427	.436		.022	.188
6	42.697	13.709	.394	.405		.021	.174
5	40.633	12.533	.359	.370		.020	.157
4	38.078	11.210	.320	.331		.019	.130
3	36.023	9.708	.276	.287		.018	.113
2	33.211	7.927	.223	.236		.017	.091
1.9	32.903	7.725	.217	.230		.016	.089
1.49	31.490	6.842	.191	.204		.015	.079
1.16	30.168	6.037	.168	.180	.606	.014	.069
1.04	29.451	5.715	.159	.173	.600	.013	.066
1.00	28.673	5.605	.155	.168	.525	.013	.053
-1.04	27.560	5.713	.158	.167	.396	.013	.036
-1.16	26.530	6.032	.168	.176	.378	.013	.036
-1.37	25.560	6.549	.183	.191	.426	.014	.047
-1.67	24.710	7.247	.203	.211	.510	.014	.067
-2.41	23.259	8.697	.246	.254	.525	.015	.085
-3.28	21.808	10.148	.288	.296	.530	.015	.101
-4.28	20.357	11.599	.331	.338	.535	.016	.116
-5.42	18.906	13.050	.374	.381	.530	.016	.130
-6.69	17.455	14.501	.416	.422	.510	.017	.135
-8.10	16.004	15.952	.459	.464	.490	.017	.139
-9.64	14.553	17.403	.501	.506	.460	.017	.132
-12.01	12.533	19.423	.561	.564	.405	.018	.116
-13.14	11.372	20.314	.585	.591		.018	.100
-13.87	10.020	20.574	.604	.609		.018	.093
-14.12	8.570	21.065	.612	.615		.022	.091
	7.010						
	5.325						
	3.640						
	1.955						
-14.12	.00	21.065	.612	.615	.405	.022	.091





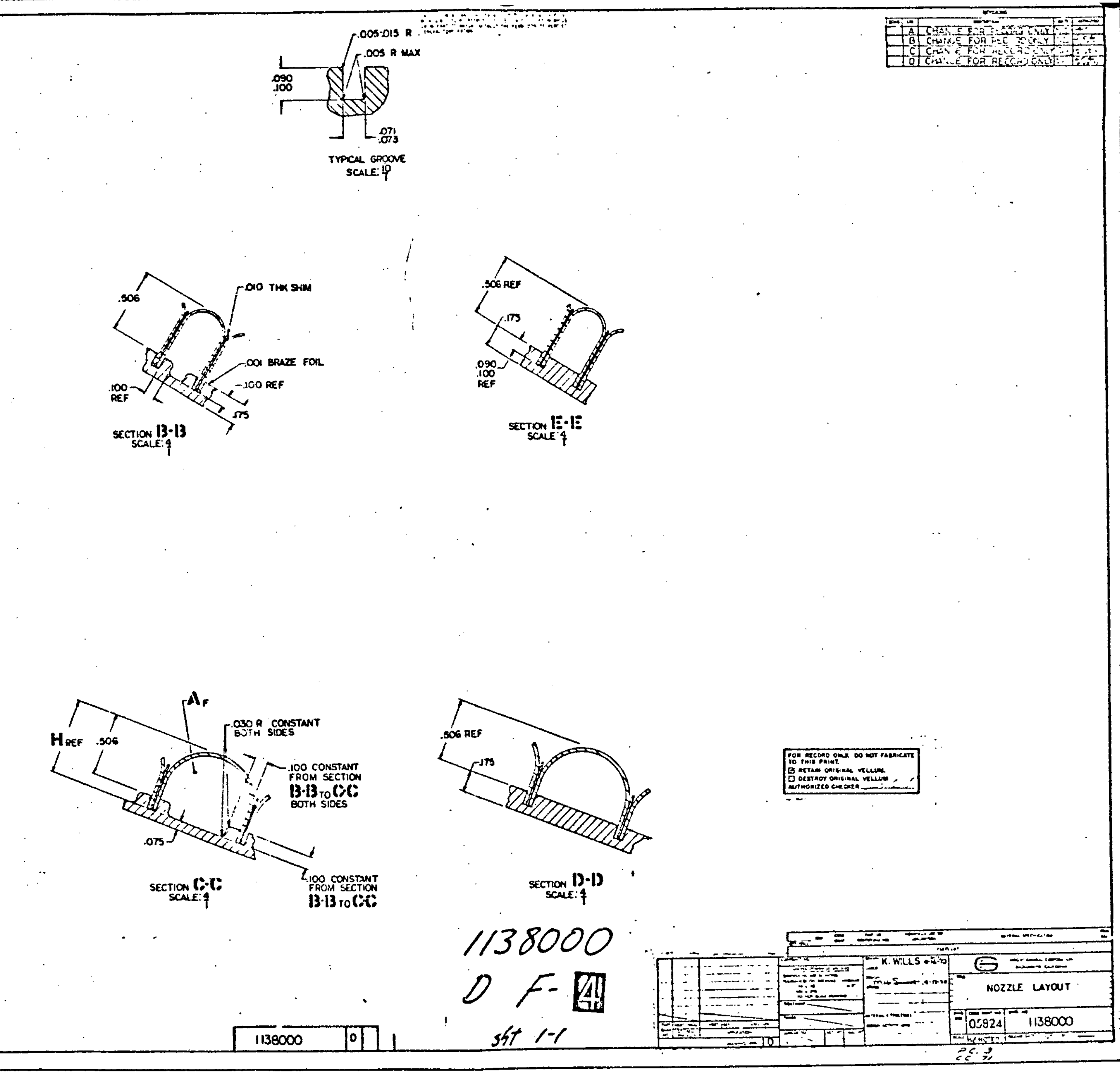


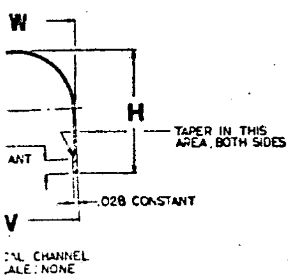


1138000
D F-3
sht 1-1

1138000	D

±.005	T ±.001	A_F
C6	028	296
	C.8	245
	C26	220
	0.8	[illegible]
	C27	248
	C.6	270
	025	250
	C24	219
	C23	202
	022	188
	C21	174
	C20	157
	C19	130
	0.8	113
	0.7	C91
	0.6	C89
	0.5	079
36	0.4	069
00	C.3	046
25	0.3	053
96	C.3	026
78	0.3	C36
26	0.4	047
0	0.4	C67
25	C15	085
50	0.5	101
35	0.6	116
60	C16	.130
C	0.7	135
30	017	.139
50	0.7	.132
05	0.8	116
	0.8	100
	0.8	.093
	022	.091
25	.022	.091





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The ARMCO 22-13-5 material properties as shown in Section I, Figure 1, permitted reduction of the flange thickness from 2.4 in., thought to be required during feasibility analyses phase, to 2.0 inches.

Although the reliability assessment shown in Section I, Table I, Item VIII A and B indicates that further reduction of thickness should be considered, such refinement can best be accomplished upon availability of statistically generated design values.

The drawing showing the method of flange and bolt cooling reflects two tiers of coolant passages through the flange. Two tiers were found to be required in order to benefit from the significant increase in the ARMCO 22-13-5 strength resulting from lowering the flange temperature achieved by the increase in cooling effectiveness.

Detail "L" of the layout drawing reveals that a groove inward of each bolt hole has been introduced. The purpose of this modification was to eliminate the possibility of flow stagnation in the annulus around the bolt in the vicinity of the pressure vessel interface.

The system as discussed above was analyzed by the thermal, stress and reliability disciplines, and as the Reliability Summary Table shows, the results obtained are fully satisfactory.

c. Nozzle Jacket

(1) <u>Pressure Vessel Mating Flange Vicinity</u>

The thickness of the jacket, at its maximum cross-section at the point of tangency with the curvature of the flange segment was reduced from 0.88 inches to 0.66 inches and linearly reduced further to 0.312 inches at the nozzle throat. This reduction was achieved through use of the more realistic ARMCO properties and by taking advantage of lower jacket temperature governed by the relationships

$$(1) \quad T_2 - T_1 = \int_0^t \frac{q''' \, t \, dt}{K_{f(T)}} \; ; \quad T_2 = \frac{q''' t^2}{2K} + T_1$$

$$(2) \quad T_1 = \frac{Q/A}{h_\ell} + T_B = \int_0^t \frac{q''' \, dt}{h_\ell \, f(T_1)} + T_B = \frac{q''' \, t}{h_\ell} + T_B$$

$$(3) \quad T_{Ave} = \frac{T_2 + T_1}{2}$$

showing the dependence of the jacket wall temperature on its thickness where:

T_2 = External Surface Temperature

T_1 = Coolant Side Wall Temperature

T_B = Coolant Bulk Temperature

q''' = Internal Heat Generation Rates, BTU/In^3-sec

Q/A = Heat Flux, BTU/in^2-sec

h_ℓ = Coolant Side Heat Transfer Coefficient, BTU/in^2-sec-°R $f(T_B, T_1 \dot{w})$

t = Jacket Thickness (inches)

K = Thermal Conductivity, BTU/in/in^2-sec-°F

Here again, reliability in excess of the allocated value was achieved. A reduction of jacket thickness should be considered in light of statistical values of material allowables when available.

It can be concluded that the design generated for the ARMCO 22-13-5 structural member of the nozzle constitutes a near optimum configuration.

d. Convergent Section

The balance of the convergent section, inclusive of the throat area is not nearly as highly stressed as the location discussed in the preceding paragraph. The chamber pressure through conversion into kinetic energy decays at the throat to 230 psia (static) level. Thus, it is immediately obvious that the hoop stress in the throat area, $\sigma = \frac{PR}{t}$, is negligible compared with the location of maximum pressure and maximum radius. The adequacy of 0.312 in. jacket thickness tentatively selected for the throat area should be examined in the future in light of dynamic stability of the flight vehicle and ground test assembly dynamic studies when such analyses become available. Any corrective steps that may be necessary are very easily accomplished by adding to or subtracting from the jacket exterior without disturbing any other aspects of the nozzle design. Thus subject to verification in the future, the design in the vicinity of the nozzle throat is considerably satisfactory.

e. Divergent Section

The design of the divergent section of the jacket was generated by considering this segment primarily as part of the coolant passage design. The gas pressure in the nozzle interior at the interface with the nozzle extension (area ratio 24:1) decays to 2.3 psia and any thickness would adequately contain the flow. However, the jacket also forms a back side closure to the U-shaped coolant channels containing flow at 1375 psia (max). It has been established that a thickness 0.075 inches, as shown in the Detail "C", would more than satisfy the reliability requirements ($.9_{17}$ was obtained as shown in the Reliability Summary Table I, Item VII M). While it would appear that there

is considerable room for weight reduction, aside from locking the statistical values of material properties, consideration of fabricability and reproducibility of tolerable variances from unit to unit generates a reluctance to recommend a thinner shell. The transition of the jacket thickness from 0.312 inches at the throat to the geometry at the aft end is depicted in Details "B", "C", "D" and "E".

f. Nozzle Aft Flange

The design shown on the attached drawing should be considered as conceptual. Although, thermal analyses have been performed, any work expended in this area, in terms of maturity can only be classified as preliminary. Finalization depends totally on the selection of the design of the mating nozzle extension flange which itself is subject to extensive analyses and development---yet to be performed. The aft flange itself is not subjected to loads of concern to the designer. The problem is to minimize the influence of the flange on the mating component of the nozzle extension. Thus, the design status (although satisfactory for ground or development flight testing without the nozzle extension) must be considered as preliminary.

2. Coolant Channels

a. Description

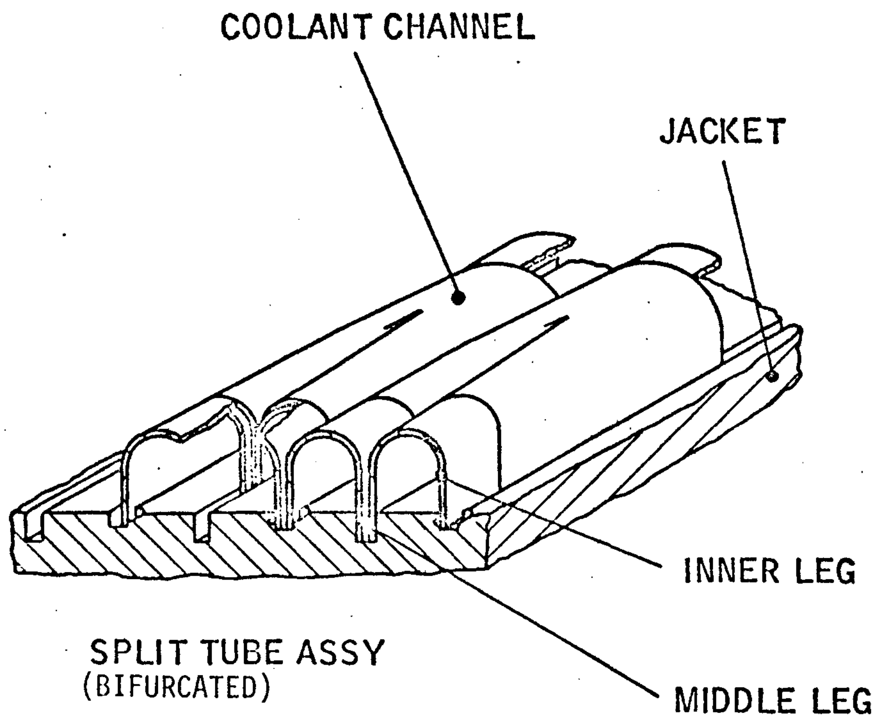
Geometries of the coolant channel at various axial locations, along with the dimensional definitions and computed flow areas,are given in attached Drawing 1138000D.

In order to avoid bifurcating (2 for 1 splice) shown in Figure 2, Option A and yet maintain structurally adequate design, a variable coolant channel thickness was adopted. At the coolant inlet at nozzle A_e/A_t = 24:1, the primary consideration in selecting the wall thickness was tube rupture caused by 1375 psi (maximum) differential pressure across the wall. It was established that at this location, a wall thickness of 0.028 inch is required. At the nozzle throat region where the probability of rupture in hoop is small compared with the coolant entrance region, the governing failure mechanisms were low cycle fatigue and tube crown temperature. Among the two, it was the heat transfer aspect that was found to dictate that a wall thickness of 0.013 $\pm$ 0.005 inch should be incorporated. In the cylindrical portion of the nozzle, the consideration of buckling led to the selection of 0.022 in. wall thickness. Between the three key locations, the wall thickness was varied linearly.

The desired wall temperature profile is governed by heat transfer coefficients, both coolant and hot gas side. However, once the optimum performance nozzle contour has been selected, the designer cannot exercise any control of the hot gas side heat transfer coefficient.

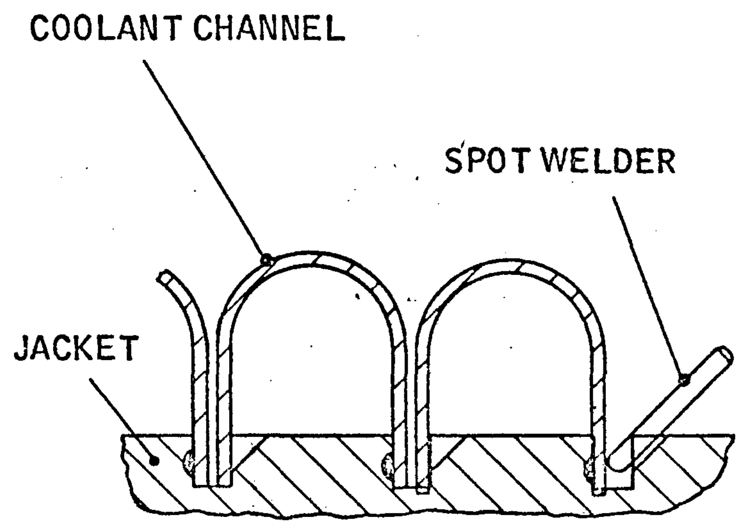
NOZZLE ASSEMBLY DESIGN STATUS REVIEW

SPLIT & "U" TUBE COOLANT CHANNEL ASSEMBLY



SPLIT TUBE ASSY
(BIFURCATED)

OPTION A



"U" TUBE ASSY

OPTION B

AEROJET NUCLEAR SYSTEMS COMPANY

FIGURE 2

The coolant side heat transfer coefficient on the other hand can be controlled within limitations of the available pressure drop and provided that a coolant Mach No. of 0.3 has not been exceeded. While the physical and transport properties cannot be engineered, the coolant velocity can. The control over the coolant velocity in the NERVA nozzle is reflected by making the legs of the U shaped channel a variable design parameter selected to suit the need. Accordingly, the terminals (entrance and exit locations) have zero leg height (except 0.100 in. provided for insertion into the jacket groove) and a maximum leg height can be found in throat region.

b. Method of Coolant Channel Attachment to the Nozzle Jacket

(1) Current Method

The process of coolant channel installation used to arrive at the nozzle assembly shown in Drawing No. 1138000D entails making 212 grooves in the interior side of the nozzle jacket. These grooves are 0.090-0.100 inch deep and 0.071-0.073 inch wide over the entire length. The coolant channels conforming to the nozzle contour are installed one at a time in grooves as illustrated in Figure 2, Option B. Only one leg of each tube is attached to the side of the groove by spot welding technique. The last tube installed (until the first brazing cycle) is held in place by friction produced by a shim driven into the space between each two adjacent legs. Gold alloy foil preplaced prior to coolant channel insertion provides the necessary brazing material.

Although the fabrication history of the NERVA Technology nozzles has proven the process to be fully satisfactory, a tube to shell braze joint failure, experienced during the ARMCO 22-13-5 to CRES 347 brazing compatibility studies, raised some questions regarding the reproducibility and reliability of the practices used. One of the test assemblies made failed at the joint at 3400 psi pressure. Sectioning of the specimen for post-failure analysis has shown that:

1. One leg of one tube of the assembly had only 0.020 inch of engagement with the jacket.
2. Improper insertion is possible and not readily detectable.
3. Spot welding technique may be less reliable than heretofore believed.

There is no quality assurance evidence that either Item 1 or 2 were the cause of failure. The most plausible failure mechanism was bowing of the channel between two spot weldments during the first brazing cycle. The relatively low mass of the coolant channel compared with the 48 inch long, 6 inch wide and 0.6 inch thick flat plate results in the plate temperature lagging the channel temperature. The attendent higher rate of the coolant channel expansion has likely been the cause of the tube leg to rise in the groove.

The likelihood of such occurrence in the nozzle during brazing is less, because of the bell shape configuration. The differential expansion of the two members probably would produce a strain in the channel rather than separation. In the cylindrical and convergent sections of the nozzle smaller intervals between spot weldment are desired. Nevertheless the possibility of the separation phenomenon cannot be ignored. Consequences of failure along with minimum success criteria are given below.

Reliability calculations included in this report have shown that in order to satisfy the reliability requirement, a minimum nozzle to jacket brazed engagement of 0.020 in. must be assured.

This indicates that not only a proper insertion has to be assured, but also that a positive means of inspection for unbrazed condition must be developed. Ultrasonic inspection was found both meaningful and useful except in the region of transition from cylindrical to convergent portion of the nozzle where the presence of the pressure vessel mating flange produces no results.

Assuming that a better means of inspection could be provided to ensure 0.020 inch minimum brazed engagement, other aspects would still render this condition unacceptable. A coolant channel only partially inserted would result in an increase in coolant flow area, thus reducing the coolant side heat transfer coefficient. The attendent protrusion into the hot stream would increase the hot gas side heat transfer coefficient. The respective changes individually even more so collectively would cause an increase in the coolant channel wall temperature voiding all reliability analyses related to this parameter.

From a heat transfer point of view insertion into 80% of the groove depth with more frequent than the 6 inch spot welding (heretofore used) intervals is required.

Thus either a more positive method of coolant channel installation inspection (probably attainable) is necessary, or a better installation method needs to be devised. Any such new method must satisfy three objectives:

1. Reduce or eliminate the dependency on inspection of proper coolant channel leg insertion.
2. Reduce or eliminate the dependency on inspection coolant channel to groove wall brazed area or presence of braze alloy.
3. Reduce or eliminate the possibility that a coolant channel with one leg shorter by more than 0.020 inch than the other will be used.

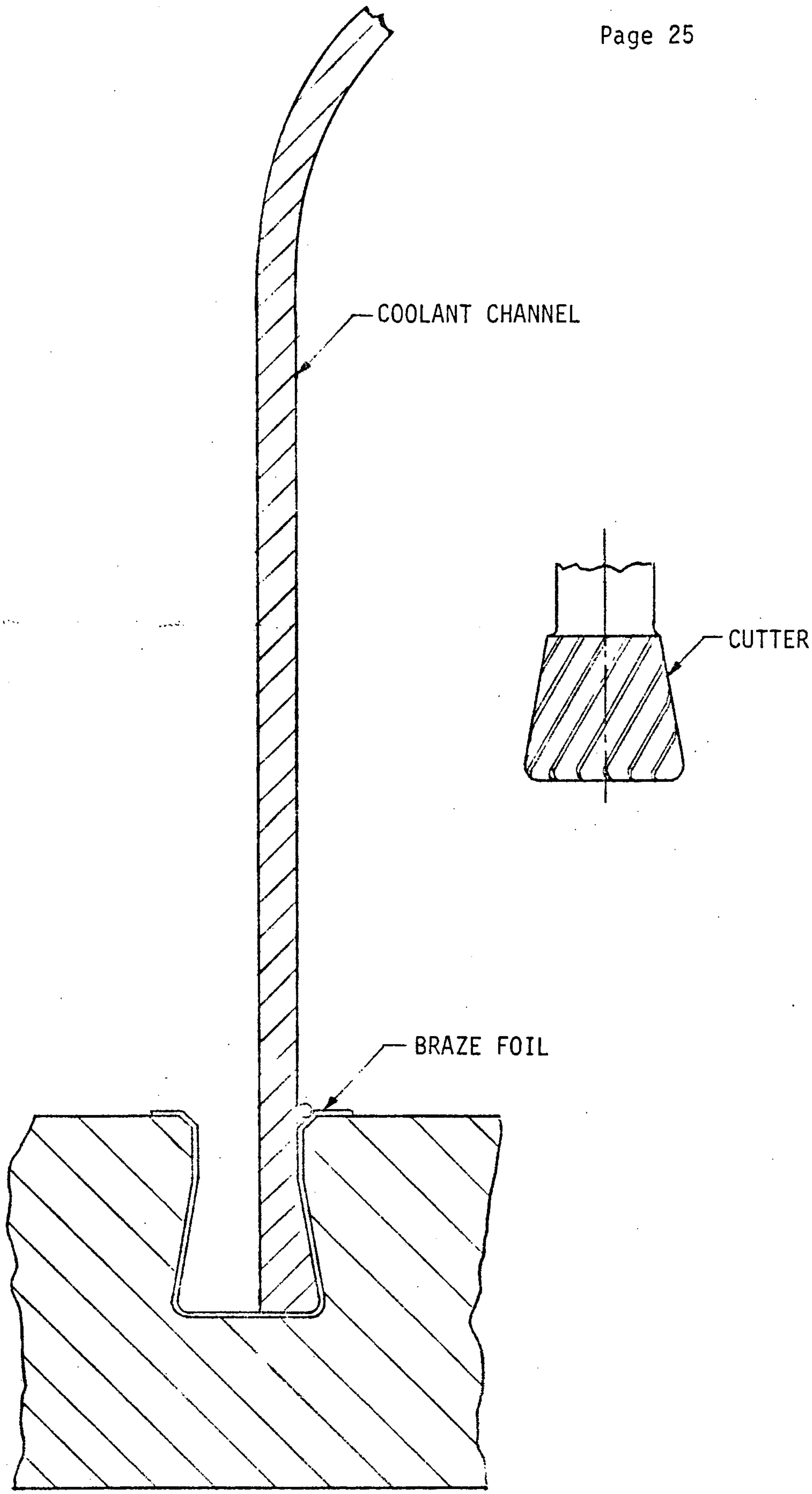
A new method of coolant channel installation is described below.

(2) <u>New Coolant Channel Installation Method</u>

The processes that would satisfy the three requirements above, are depicted in Figure 3 through 6.

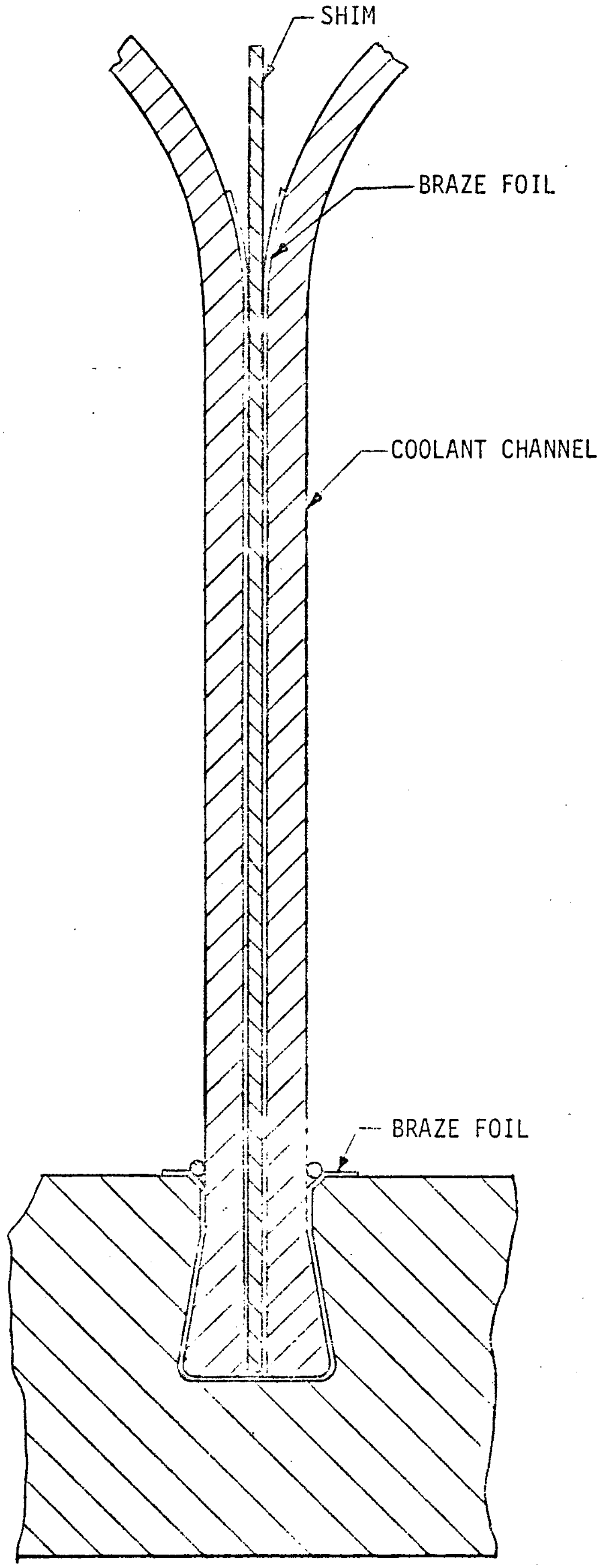
Figure 3 shows installation of the first channel. The manufacturing steps up to this point are as follows:

1. Machine the jacket conventionally producing constant width and constant depth grooves.
2. Use the cutter tool shown to produce the tapered shape. The narrow smooth shank of the cutter is piloted between parallel portions of the groove already made to prevent lateral drift.
3. Preplace braze foil and wire---if desired. It is believed that this brazing material is superflous and it can be eliminated.



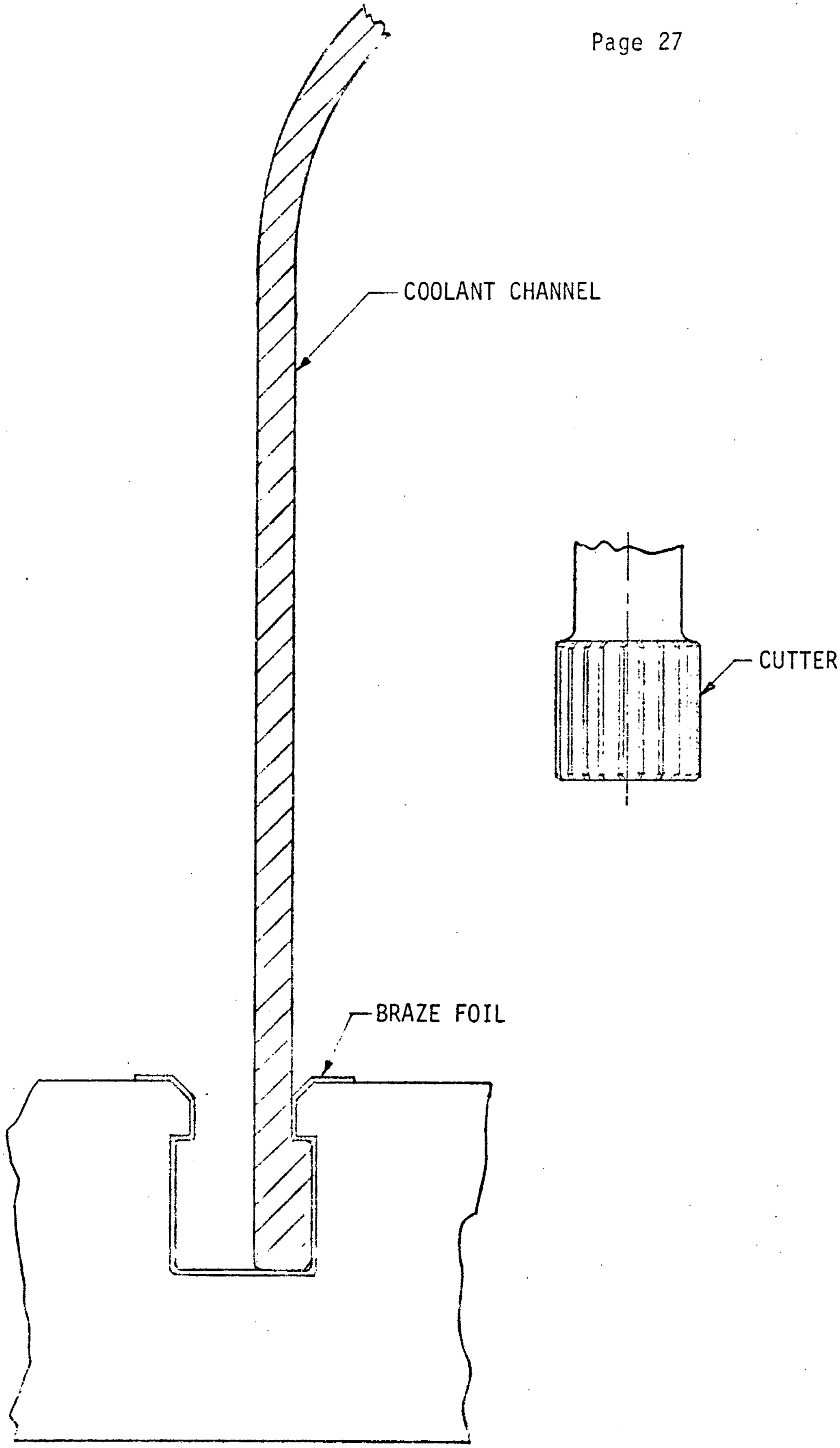
INTERLOCKED COOLANT CHANNEL DESIGN
BEVELED GROOVE

FIGURE 3



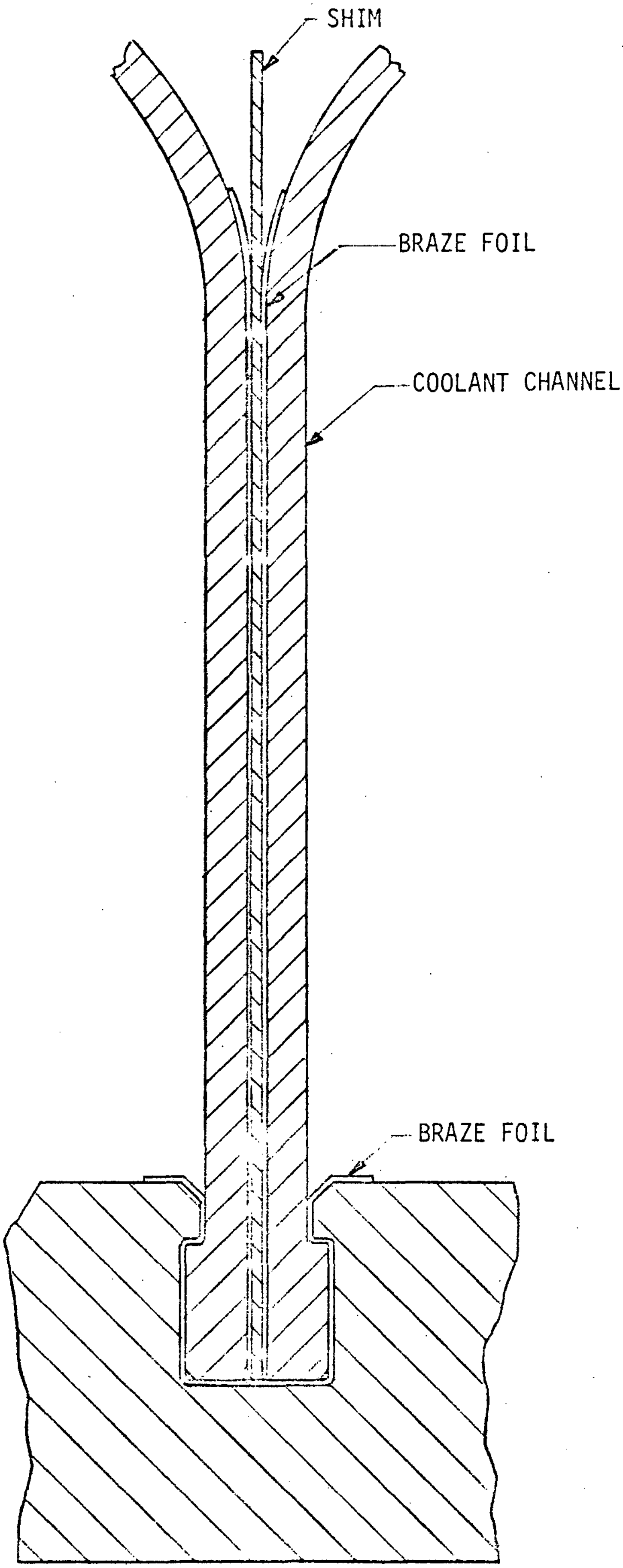
INTERLOCKED COOLANT CHANNEL DESIGN
BEVELED GROOVE

FIGURE 4



INTERLOCKED COOLANT CHANNEL DESIGN
RECTANGULAR GROOVE

FIGURE 5



INTERLOCKED COOLANT CHANNEL DESIGN
RECTANGULAR GROOVE

FIGURE 6

4. Install channel by pushing downward. The chamfer at the top of the groove guides the tube legs. Use enough force to snap the channel into place.
5. Use Step 4 to install the adjacent channel.
6. Insert shim with foil around it (this braze foil is essential and cannot be eliminated) to fill the gap and force the legs against the groove wall as shown in Figure 4.

During installation the channel can be removed---if required---by prying the tube out and starting at either end. The tapered shape will facilitate removal.

Figure 5 and 6 depict essentially the same concept and process sequence. It is envisioned, however, that preforming the braze foil and installing it would be more difficult and more costly. Channel removal for replacement would be quite difficult.

In either model a danger exists that during tube installation the preplaced foil would be damaged. It is recommended to delete it from the process.

Advantages gained: If the channel legs are not fully inserted the shim will not go in. But once installed and shimmed, the channels are mechanically locked and separation of the two members is not possible in handling or brazing. If preplaced braze foil is used it will be of no consequence how much braze area was effectively achieved.

The method requires no special inspection techniques other than standard dimensional inspection. The only criteria is the ability to drive the shim in.

Elimination of the preplaced foil and wire may offset the cost of additional machining.

C. ANALYSES

The results of analyses performed by each of the supporting disciplines are given in each of the respective Appendices and will not be repeated here. Only highlights and some clarifying aspects will be brought to the reader's attention in order to provide a better understanding of the degree of the completeness of analytical and design maturities attained.

1. Material Properties

Until cursory data on forged ARMCO 22-13-5 strength become available, it was assumed that such properties would be significantly below the material strength obtained from rolled plate. Accordingly, the minimum design allowables were assumed to be no higher than those of Hastelloy X.

Either assumption turned out to be overly pessimistic. Test specimens obtained from ARMCO close die forgings (3 units) showed no reduction in either ultimate or yield strength with respect to rolled plate room temperature data.

It was thus assumed that the more extensive rolled plate average values data is representative over the temperature range shown in the Summary, Figure 1. 20% of the average values was discounted to establish the minimum design limit.

2. Nuclear Heating and Thermal Analyses

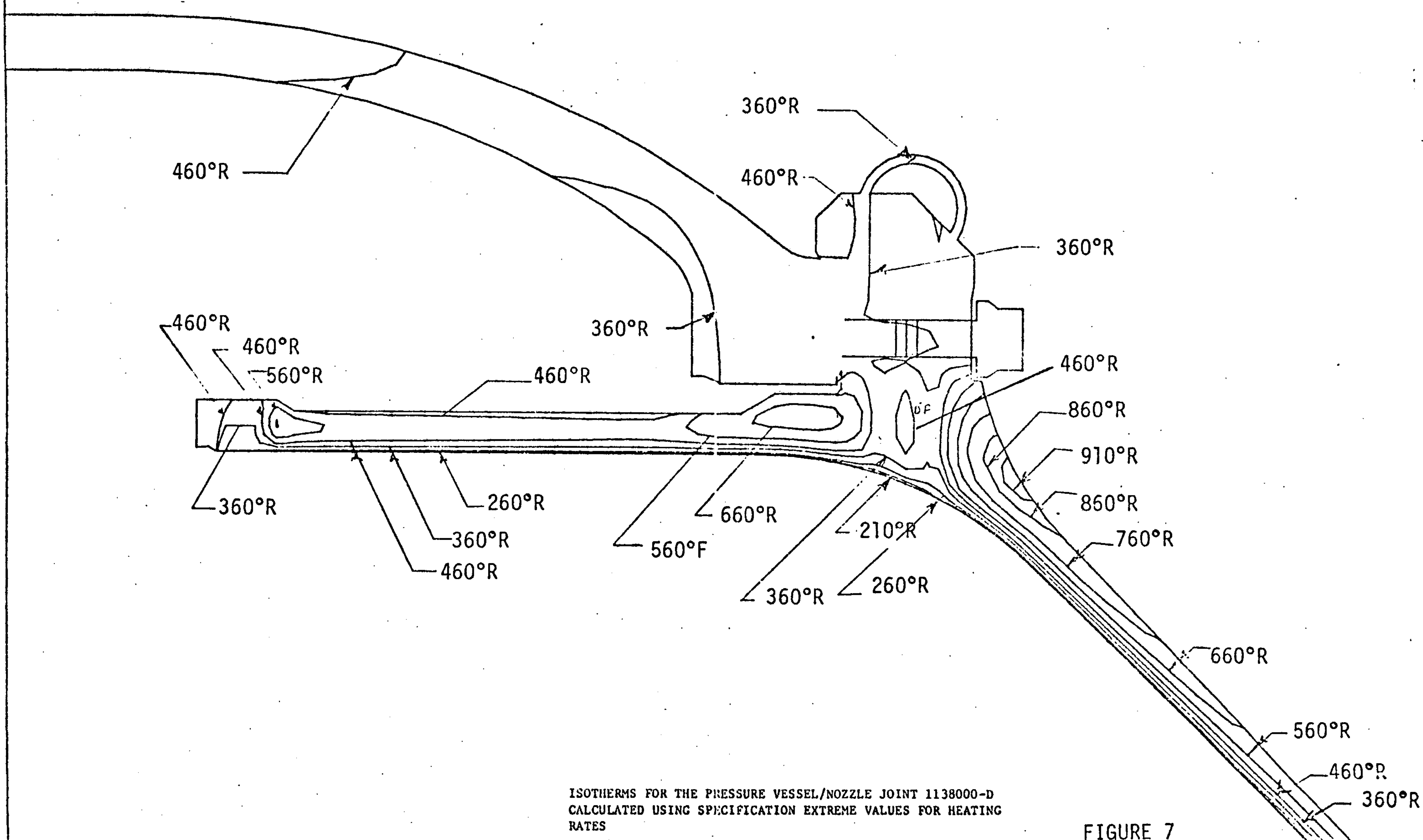
The effect of internal heat generation in the coolant channel walls were not calculated. Such effects, however, are known to be low enough to be ignored. The nozzle jacket was analyzed using both the maximum (spec extreme) and nominal values. The results of thermal analyses based on the two sets of values are shown in Figure 7 and 8 respectively. It can be seen that in most areas the isotherms are about 100°R lower for nominal gamma heating values, except just underneath the flange where a difference of as much as 400°R is observed.

Thermal analyses to the coolant channels reflect no more than steady state conditions at normal, malfunction, throttling modes at the start and end of life. Normal mode at the end of life was found to produce maximum severity.

In addition, study of variance influence and sensitivity was initiated.

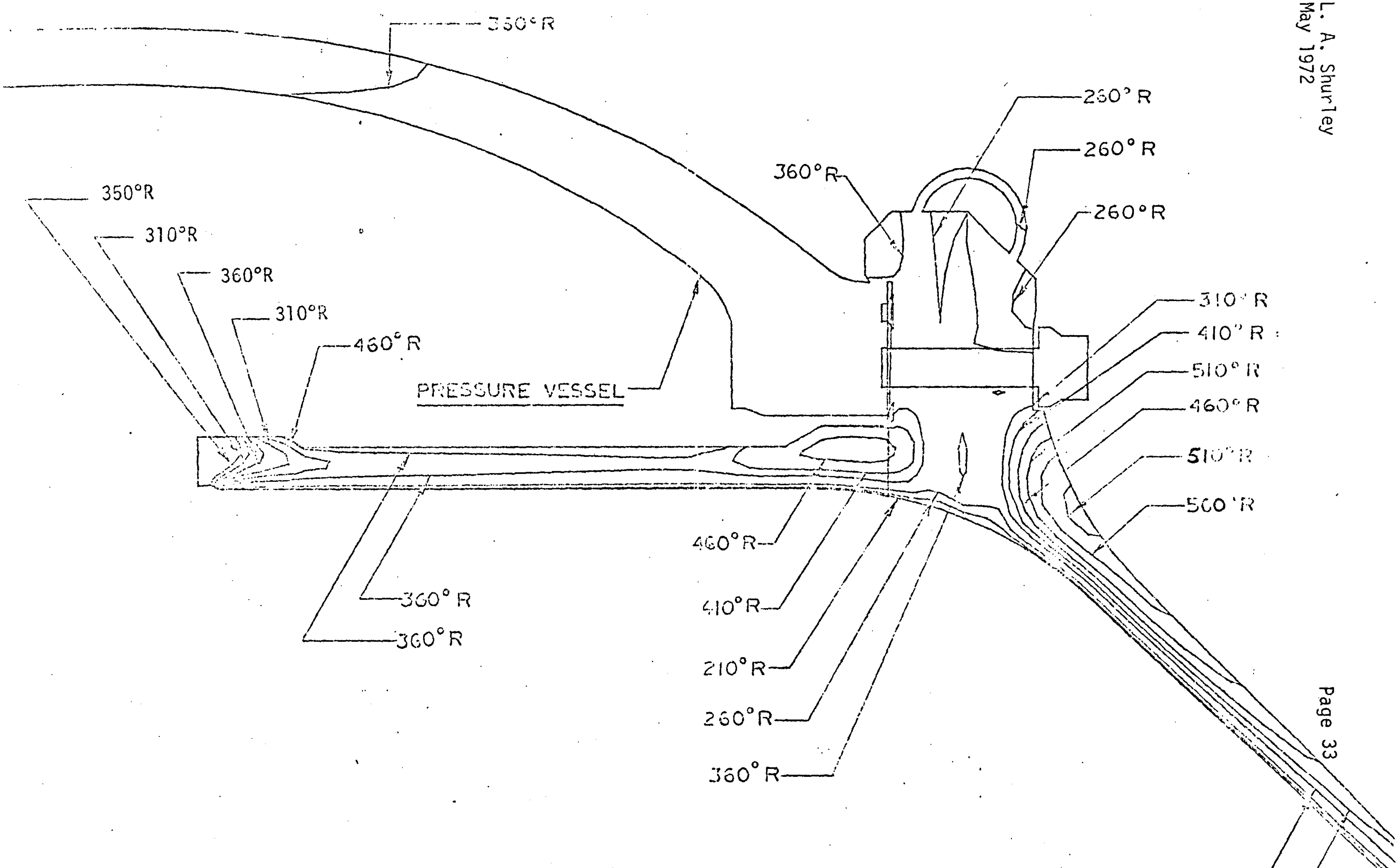
Table II represents the first attempt to provide a statistical analysis of temperature data for use in analysis of coolant passage reliability (FMA VII). The data was not used in the reliability calculations reported in Appendix because it was not available at the time the reliability calculations were conducted.

The temperature values used for the analysis were based on specification extreme conditions, however, the difference is relatively minor. The tube wall temperature (T_{wg}) at the max flux point is 1471°F for specification extreme conditions and 1452°F for nominal conditions. The corresponding temperatures in the barrel section are 1060°F and 1041°F. A reduction in temperature of 20° would have very little effect on material strength, however, it is recommended that future calculations use the sensitivity analysis method to provide increased confidence in the reliability calculations. The additional computer



ISOTHERMS FOR THE PRESSURE VESSEL/NOZZLE JOINT 1138000-D
CALCULATED USING SPECIFICATION EXTREME VALUES FOR HEATING
RATES

FIGURE 7



Isotherm Plot

2.0 inch Flange

Ref. Computer Run

Nominal Temperature

Joe: 428237,2,100 23 Feb. 1972

FIGURE 8

TABLE II

ΔP AND ΔT_B SENSITIVITY - PRELIMINARY

USING 25104 NOZZLE HEAT TRANSFER PROGRAM

① RUN NUMBER	② PARAMETER	③ $N\sigma$	④ $(N\sigma)x(\Delta PARA)$	⑤ TWG(°R) ε = 24/1	⑥ TWG(°R) MAX FLUX PT.	⑦ ΔP	⑧ $\frac{\partial \Delta P}{\partial PARA}$	⑨ ΔT_B	⑩ $\frac{\partial \Delta T_B}{\partial PARA}$	⑪ TWG(°R) BARREL ε = -14.12	⑫ COMMENTS
COP S-001 NOM	NOM	-	-	616	1912	161.7	-	138.2	-	1501	-
COP S-002 PC + 1 SIGMA	PC	+1	2.1496	616	1912	161.7	0	138.2	0	1501	NOM = 450
COP S-003 PC +2.326 SIG	PC	+2.326	5.0	616	1912	161.7	0	138.2	0	1501	NOM = 450
COP S-004 TC +2.326 SIG	TC	+2.326	45.0	627	1932	163.8	+2.1	140.2	+2.0	1520	NOM = 4252
COP S-005 TC +1 SIG	TC	+1	20.0	624	1921	162.6	+0.9	139.0	+0.8	1509	NOM = 4252
COP S-006 PIN +2.326 SIG	PIN	+2.326	53.0	606	1909	157.2	-4.5	139.3	+1.1	1499	NOM = 1375
COP S-007 PIN +1 SIG	PIN	+1	23.0	612	1911	159.6	-2.1	138.6	+0.4	1500	NOM = 1375
COP S-008 TIN +2.326 SIG	TIN	+2.326	2.20	612	1908	164.4	+2.7	138.1	-0.1	1499	NOM = 60.7
COP S-009 TIN +1 SIG	TIN	+1	0.95	614	1910	163.0	+1.3	138.2	0	1500	NOM = 60.7
COP S-010 TM +2.326 SIG	TM	+2.326	.001	621	1953	160.8	-0.9	137.1	-1.1	1519	INSIGNIFICANT
COP S-011 WC +2.326 SIG	WC	+2.326	1.7	608	1908	165.6	+3.9	135.2	-3.0	1495	NOM = 77.8
COP S-012 WC +1 SIG	WC	+1	.73	498	1910	163.9	+2.2	137.1	-1.1	1498	NOM = 77.8
COP S-013 R +2.326 SIG	R	+2.326	.010	616	1909	161.7	0	138.2	0	1501	
COP S-014 AF +5.0%	AF	+2.326	+590	638	1934	142.8	-18.9	136.6	-1.6	1532	
COP S-015 AF +2.15%	AF	+1	+2.15%	626	1922	153.3	-8.4	137.5	-.7	1514	
COP S-016 CL +15%	CL	+2.326	+15%	724	2000	155.4	-6.3	131.4	-6.8	1613	
COP S-017 CL +6.45%	CL	+1	6.45%	649	1949	158.0	-3.7	134.8	-3.4	1547	
COP S-018 CG +20%	CG	+2.326	+20%	501	1733	145.1	-16.6	120.5	-17.7	1336	
COP S-019 CG +8.6%	CG	+1	+8.6%	567	1837	154.9	-6.8	130.9	-7.3	1433	
COP S-020 K1 +10%	K1 = 1.10	+2.326	10%	616	1912	161.8	+0.1	138.2	0	1501	NOM = 1.00
COP S-021 K1 +4.3%	K1 = 1.043	+1	4.3%	616	1912	161.8	+0.1	138.2	0	1501	NOM = 1.00
COP S-022 K3 + 10%	K3 = 1.54	+2.326	10%	616	1912	165.8	+4.1	138.2	0	1501	NOM = 1.40
COP S-023 K3 + 4.3%	K3 = 1.46	+1	4.3%	616	1912	163.5	+1.8	138.2	0	1501	NOM = 1.40
COP S-024 PFM +10%	PFM =1.922	+2.326	10%	616	1912	169.5	+7.8	138.1	-0.1	1502	NOM = 1.747
COP S-025 PFM +4.3%	PFM = 1.822	+1	4.3%	616	1912	165.0	+3.3	138.2	0	1501	NOM = 1.747
COP S-026 ε =+10%	ε = .935	+2.326	10%	616	1900	175.1	+13.4	152.3	+14.1	1490	NOM = .850
COP S-027 ε = +4.3%	ε = .887	+1	4.3%	616	1907	167.7	+6.0	144.4	+6.2	1496	NOM = .850
COP S-028 K = +10%	K	-	10%	634	1894	157.7	-4.0	138.5	+0.3	1506	K OF TUBE
COP S-029 K +5%	K	-	5%	638	1912	157.1	-4.6	137.9	-0.3	1519	K OF TUBE

NOM - ALL INPUT NOMINAL
PC - CHAMBER PRESSURE
TC - CHAMBER TEMPERATURE
PIN - COOLANT INLET PRESSURE
TIN - COOLANT INLET TEMPERATURE

TM - TUBE WALL THICKNESS
WC - COOLANT FLOW RATE
R - CHAMBER RADIUS
AF - COOLANT FLOW AREA
CL - CONSTANT LIQUID SIDE H.T. EQN.

CG - CONSTANT GAS SIDE H.T. EQN.
K_1, K_3 - CONSTANT USED TO PREDICT PRESSURE DROP
PFM - PRESSURE MULTIPLIER
ε - HEATED AREA FACTOR
K - THERMAL CONDUCTIVITY TUBE METAL

time required is negligible, and it provides an accurate estimate of temperature variation due to the independent design/operations variables.

The E25104 program was revised by J. J. Williams prior to contract termination, and renamed E25107. The new program corrected some minor problems, and was to be used for calculation of the temperature mean and variation for use in the reliability analysis of the coolant passage.

The following is a description of the meaning of each column heading.

Column

1. Computer run number.
2. The independent parameter being varied.
3. $N\sigma$ is the number of standard deviations the parameter listed in Column 2 was increased.
4. $(N\sigma) \times (\Delta \text{ Parameter})$ is the actual value by which the parameter in Column 2 was increased.
5. T_{wg} is the calculated gas side tube wall temperature at the area ratio of 24:1 using nominal values for all the independent parameters except the one listed in Column 2.
6. T_{wg} (max flux). Same as above except this value of T_{wg} is calculated at the point of maximum thermal flux (located just above the throat).
7. ΔP is the change in coolant pressure between the nozzle inlet and outlet. These values of ΔP are calculated using nominal values for all the independent parameters except the one listed in Column 2.
8. $\frac{\partial \Delta P}{2 \text{ para}}$ is the change in the ΔP across the nozzle produced by varying the independent parameter shown in Column 2 while holding all others constant.

9. ΔT_B is change in coolant bulk temperature between nozzle inlet and pressure vessel plenum.

10. $\frac{\partial \Delta T_B}{2\ para}$ is the increase or decrease in coolant bulk temperature caused by the variation in the parameter listed in Column 2, with all other independent parameters held constant.

11. T_{wg} is gas side tube wall temperature in the nozzle barrel section at area ratio of -14.12:1.

12. This column lists the nominal value of the parameter shown in Column 2.

A comment is in order relative to the thermal analyses included in Appendix C. Reader will note that the analyses performed to determine the temperature gradient from the coolant channel crown to the cylindrical portion of the nozzle jacket minimum internal heat generation rates were used. This was done deliberately (not as a result of analyst's error) to generate minimum temperature in the tube crown (300°R were added) so as to generate a maximum gradient which constitutes a more severe environment. Such information was desired and was used for computing variances from mean values in the Reliability calculations, Appendix F, of the coolant channels with respect to buckling failure mechanism.

3. Stress Analysis

Analyses related to the nozzle jacket reflect primarily refinements and calculations related to new ARMCO 22-13-5 material properties. The coolant channel analyses contain only new aspects, predominantly determination of strain and low cycle fatigue under hold conditions, inclusive of operation at wall temperature of 1600°F (throat region) resulting from 4500°R gas temperature. Conventional failure mechanisms such as tube rupture were analyzed and certified as not credible in the prior contract year. The most significant contribution to this document manifests itself in documented methodology developed and used.

4. Reliability Analyses

The basis for the analyses included in Appendices E and F were all thermal and stress calculations completed to date and inclusive of information provided in Appendices A through D. Not all failure modes and the mechanism contained therein were analyzed. From the contents of the FMA document given below

I. Physical Description

II. Functions' Description

III. Functional Failure Cause and Effect Summary

IV. Failure to Produce the Required Thrust and I_s

V. Failure to Generate the Required Temperature Rise through the Nozzle

VI. Failure to Generate the Specified Pressure Drop through the Nozzle

VII. Failure to Transport Propellant Through the Nozzle Coolant Circuit

VIII. Failure to Close the Aft End of the Pressure Vessel or Support the NSS (Contain the Hot Gas)

IX. Failure to Provide for Diagnostic and Engine Control Instrumentation

only Items VII and VIII were here documented.

Relative to Item IV, the attained reliability with respect to hot gas and coolant channel containment (Sections VII and VIII) and previously reported 97.7% theoretical performance,meeting the requirement of specified thrust and specific impulse is virtually assured.

Relative to Items V and VI, the parameter sensitivity analyses have been just initiated (Table II). The influence of variances has not been treated probabilistically, but these are not nearly as important (category of Failure I or II at the most) as Items VII and VIII where category levels of III and IV are involved.

Item IX, although important does not lend itself readily to analytical treatment. Conformance to the requirements will be assured by inspection with relatively little left to the control of the designer.

Thus the analyses contained in the Appendices are limited to the reliability assessments with respect to failure modes and mechanisms identified in FMA Sections VII and VIII respectively.

A good many of these calculations are quite conventional, straight forward and self explanatory. However, there are few mechanisms of special interest which are worthy of discussion provided below.

a. Coolant Channel Low Cycle Thermal Fatigue

Data related to this failure mechanism was obtained in two phases. Phase I (less expensive), produced extensive information under compression-compression cycling, but no hold conditions over temperature range of 1000°F to 1600°F. Phase II (more expansive) provided few points under compression-10 minutes hold cycling conditions at 1400°F and 1600°F. These two temperatures were selected, because they represent maximum coolant channel temperature resulting from 4250°R and 4500°R hot gas temperature respectively.

For clarity, only these two temperature regimes are shown in Figure 9. The two lines of negative slopes relate mean cycling life to induced strain. The solid horizontal lines at three different strain levels indicate the spread of data under no-hold conditions. Few identified data points under 10 minute hold time for the same strains were superimposed for 1400°F and 1600°F temperatures. It can be seen that no degradation in cycling life is evident. If anything a slight increase is indicated. Due to the fact that they do not appear to cause an increase in variance, all data was pooled and statistically (.99/.95) presented in Figure 10. Track has been kept however of the small (not detrimental) differences between no-hold and hold conditions.

L. A. Shurley
May 1972

CRES 347 CYCLES TO FAILURE VS STRAIN
MEAN CURVES AND DATA SPREAD FOR NO HOLD TESTS
PLUS TEST DATA POINTS FOR 10 MIN HOLD TIME TESTS

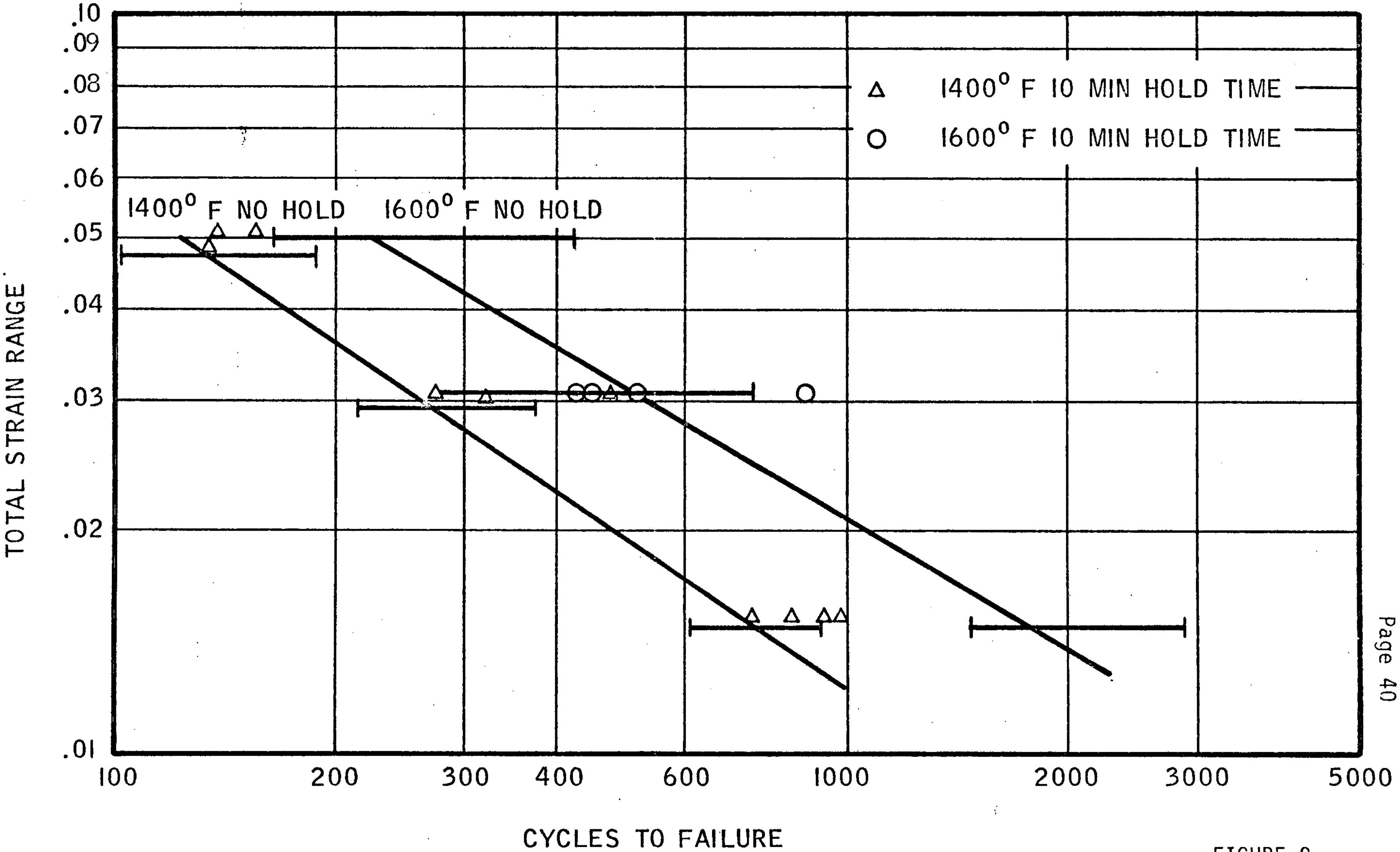


FIGURE 9

CRES 347 CYCLES TO FAILURE VS STRAIN .99/.95 LINES
(NO HOLD TIME EXCEPT AS INDICATED FOR 1400° F AND 1600° F)

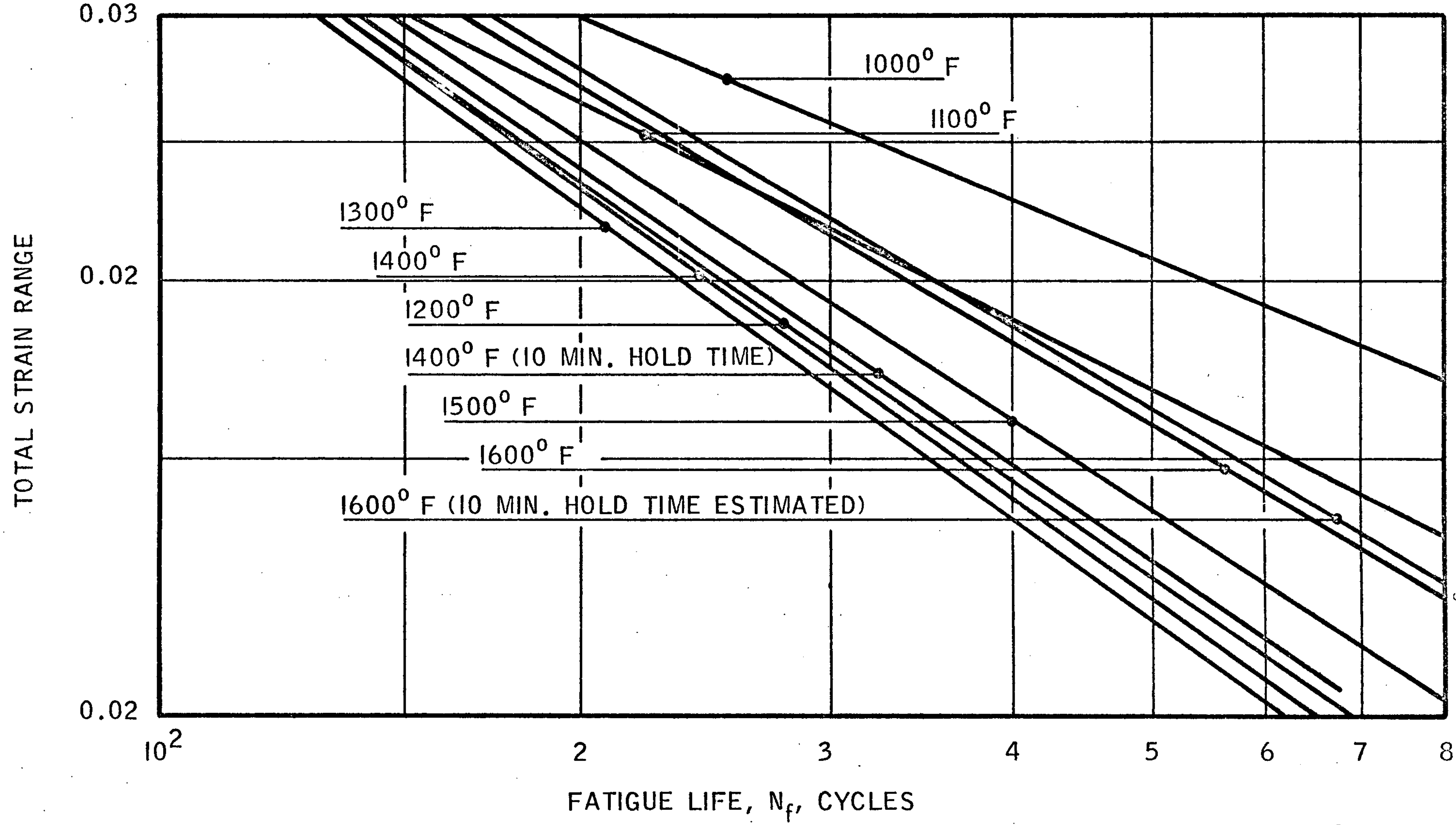
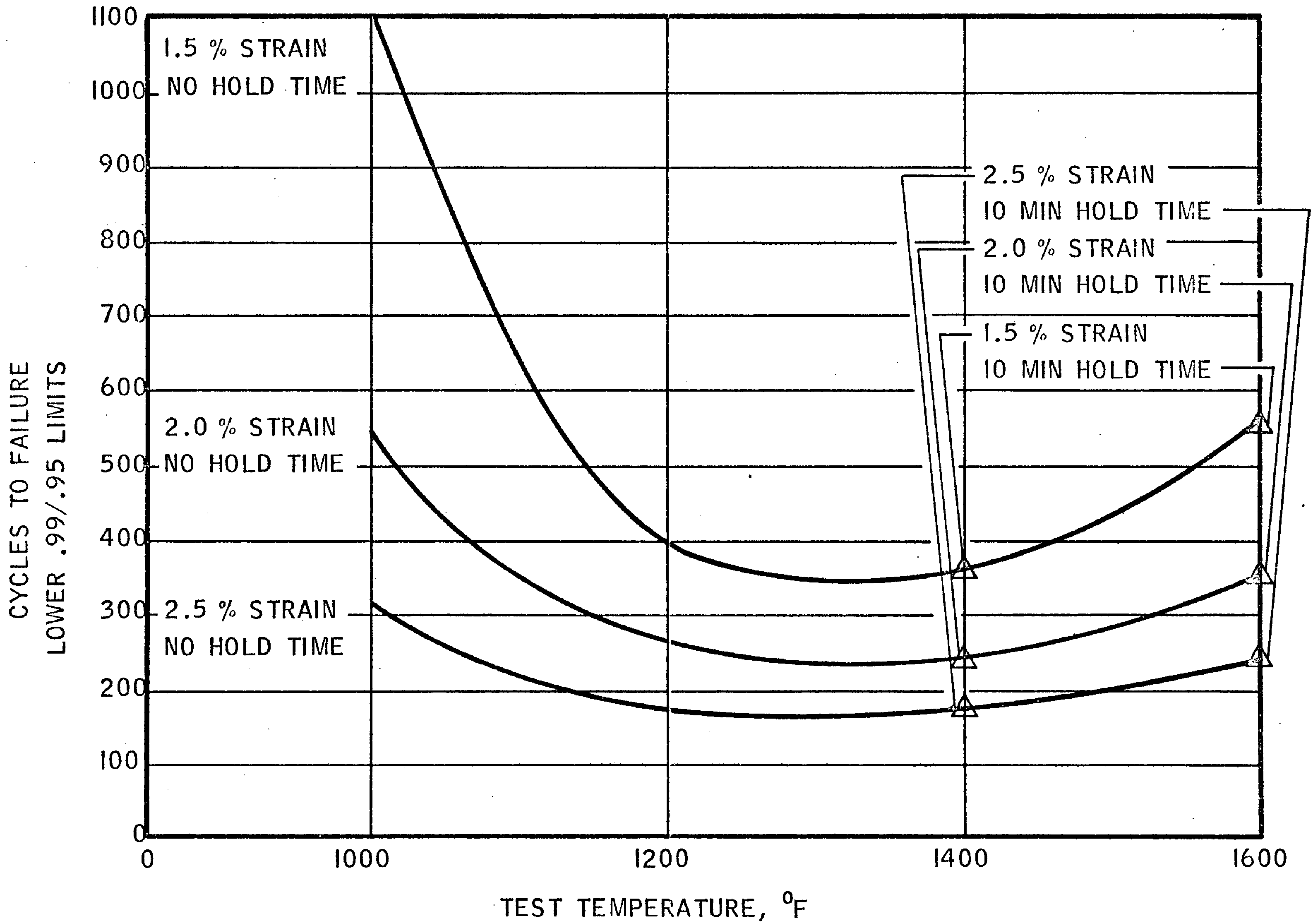


FIGURE 10

CRES 347 CYCLES TO FAILURE VS TEMPERATURE



L. A. Shurley
May 1972

FIGURE 11

For clarity,data from Figure 10 at selected strains of interest has been cross plotted to produce Figure 11. This plot (statistical values) of cycling life as function of temperature at strain levels determined to exist at various engine operation modes was used to conduct the reliability calculation. Appendix D, Table I, Page 7 provides calculated strains at the nozzle throat region and the barrel sections at gas temperature of 4250°R and 4500°R. The gas side wall temperatures in the barrel section as shown include 300°R uncertainty in the gas temperature. Examination of the corresponding strain levels and relating these to Figure 11 indicates that the coolant channels in the barrel section possess (.99/.95) life approaching 400 cycles. In excess of 300 cycles, life is exhibited by the channels at the throat at 4250°R gas temperature. The strain calculations conducted and shown in Appendix D, page 7 indicate that a maximum strain takes place not at the tube crown, but at the side, 55° away from the crown.

At 4500°R the tube crown (1000°F and 0.021 strain) exhibits approximately 340 cycles life. The side of the tube at maximum strain location (1150°F and 0.0245 strain) exhibits about 200 cycles life. The calculated reliability of $.9_{7}64$ indicates that operation at 4500°R is permissible with respect to cycling life.

b. Coolant Channel Erosion

Maximum heat flux of 21 Btu/in^2-sec computed for the nozzle throat region is well below burnout heat flux of approximately 30 Btu/in^2-sec for hydrogen cooled passages. Likewsie the design wall temperature of 1470°F constitutes a comfortable margin with respect to 2100°F at which signs of incipient erosion have been observed in the past. There are no strict scientific data on rocket nozzle firings directly applicable to NERVA engine operations.

Chemical propulsion system intrisically produce either oxidizing or carburizing atmospheres either of which produces deleterious effects on CRES 347 at 1500°-1600°F range. Neither of these phenomena takes place in the NERVA nozzle where only hot hydrogen is present.

Ignoring this difference in the past and examination of several rocket systems history led to an assessment of reliability with respect to erosion of 0.7.

Obviously this was not a realistic approach. A better approach is to examine information available from NERVA Technology experience. The difficulty here was that the program had no failures, except those few deliberately induced for the sake of science. To establish some analytical tools certain assumptions as listed below had to be made.

(1) An average temperature for incipient erosion was postualted to be 2025°F compared with 2100°F calculated from induced failure.

(2) A lower limit reflecting assumed data scatter and analytical uncertainty was assumed to be 1950°F as supported by evidence that with braze alloys with melting temperature of 1800°F gone, CRES 347 coolant channels remained unaffected until 43% of coolant flow reduction was made.

Under the above assumptions a reliability of $.9_{9}67$ was obtained compared with $.9_{6}89$ allocated for Category III failure.

The required reliability can be met even if:

(1) Coolant channel gas side wall temperature of 1600°F was induced by 4500°R gas temperature.

(2) The lower limit and mean erosion temperature were 1850°F and 2000°F respectively.

Within the above rational and assumptions the coolant channel erosion does not appear as a credible failure mechanism.

c. Coolant Channel Buckling

A report on the subject, based on experimentation was published by North American Rockwell (Columbus, Ohio) which was used to guide the design.

The buckling phenomenon is postulated to be restricted to the cylindrical portion of the nozzle where the coolant channel radius to the wall thickness ratio (R/t) and the temperature difference between the coolant channel wall and the jacket ($T_{wall} - T_{jacket}$) make such occurrence more likely than in other locations of the assembly.

In order that success probability be not overestimated, and to ensure that this failure mechanisms will not occur during the reactor development phase, it was postulated that:

(1) Temperature stratification will produce some zones where the reactor exit gas will take place.

(2) The stratification will produce some zones where the gas temperature will exceed 4500°R by 300°R for T_o = 4800°R.

(3) That the 300°R excess will produce 300° increase in the coolant channel wall.

The last assumption is a very conservative one in light of the fact that the ratio of coolant side to gas side heat transfer coefficients in this region produces a change in wall temperature equal to about 1/3 of the change in the gas temperature. Thus an increase in wall temperature of only 100° should be attributed to gas temperature stratification.

Nevertheless, within the assumptions made the required reliability requirement of $.9_{6}89$ for failure Category III has been met.

In conclusion, with the exception of possible adoptation of the new method of coolant channels' attachment, the reliability calculation show that no design changes to the configuration here discussed are necessary.

APPENDIX A

2 DIMENSIONAL THERMAL ANALYSIS

OF NOZZLE/P.V. JOINT

2.0 INCH FLANGE

AEROJET NUCLEAR SYSTEMS COMPANY

SACRAMENTO, CALIFORNIA

TO: L. A. Shurley

15 February 1972
JJW:jm N8110R:72-029

FROM: O. J. Demuth

SUBJECT: Transmittal of Report N8110R:72-029 for Project 141

DISTRIBUTION: R. G. Ackerman, R. H. Coppo, J. L. Pickering, K. Sato, J. L. Watkins, J. J. Williams, G. M. Witcraft

ENCLOSURE: (1) Steady State Temperatures for the NERVA Nozzle/Pressure Vessel and Reflector Joint Number 1138000-D Using Specification Extreme Values for Nuclear Heating Rates, ANSC Report No. N8110R:72-029, dated 15 February 1972

Attached hereto as Enclosure (1) is the thermal report on the steady state, specification extreme, temperature distribution in the ARMCO 22-13-5 nozzle/pressure vessel and reflector joint number 1138000-D. This work was conducted for Project 141, Work Statement 5e.

O. J. Demuth

O. J. Demuth, Supervisor
Thermophysics Section
Engineering Staff Department

CLASSIFICATION CATEGORY
Unclassified
O. J. Demuth 2-16-72
CLASSIFYING OFFICER DATE

ENCLOSURE (1)

N8110R:72-029

ENGINEERING OPERATIONS REPORT

STEADY STATE TEMPERATURES FOR THE NERVA
NOZZLE/PRESSURE VESSEL AND REFLECTOR
JOINT NUMBER 1138000-D USING SPECIFICATION
EXTREME VALUES FOR NUCLEAR HEATING RATES

PROJECT 141, WORK STATEMENT 5e

15 FEBRUARY 1972

J. J. WILLIAMS

J J Williams

APPROVED:

K Sato
K. SATO, MANAGER
ENGINEERING STAFF DEPARTMENT

CLASSIFICATION CATEGORY
Unclassified
2/16/72
CLASSIFYING OFFICER DATE

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FIGURE LIST

STEADY STATE TEMPERATURES FOR THE NERVA NOZZLE/PRESSURE VESSEL AND REFLECTOR JOINT NUMBER 1138000-D USING SPECIFICATION EXTREME VALUES FOR NUCLEAR HEATING RATES

I. INTRODUCTION

Thermal analyses were performed to determine the two-dimensional, maximum expected, steady state temperature distribution in the ARMCO 22-13-5 nozzle/pressure vessel and reflector joint for normal flight operating conditions. This assembly is shown in Reference (a) and has the designation 1138000-D.

The analysis was conducted in compliance with Reference (b) and as requested, tolerances were applied to the parameters so that maximum temperatures were predicted for steady state, normal flight operating conditions. Results of a prior analysis on a similar configuration are reported in Reference (c).

This report details all aspects of the current analyses.

II. SUMMARY

The nozzle/pressure vessel joint number 1138000-D was analyzed to determine steady state temperatures for normal flight conditions using values for all thermal parameters adjusted to yield maximum temperatures.

Computed temperatures are shown in isotherm plot form. The maximum calculated joint temperature is 478°F in the initial contraction section of the nozzle. This is lower than the previously computed temperature of 722°F (Reference (c)) for the nominal thickness configuration at the same location. The principal reason for the decrease in maximum temperature is believed to be the reduction in wall thickness from a nominal value of 0.88 inches to 0.65 inches.

III. TECHNICAL DISCUSSION

A. CONFIGURATION DESCRIPTION

The configuration analyzed is the pressure vessel/nozzle joint described in Reference (a). The total bolt coolant flow was retained at 3 lb/sec

for 108 bolts. As in Reference (c) there are 108 rectangular grooves (0.055 inches on a side) through which a total of 1 lb/sec of hydrogen could flow through the annular gap between the inside of the pressure vessel and the nozzle at the bolt surface. The purpose of this flow is to provide additional cooling in the gap area. The dimension of 0.055 inches was selected because it resulted in a dynamic pressure of 20 psi in the groove which is the approximate value required to maintain an appropriate pressure drop through the flow passage.

B. MATERIAL PROPERTIES

Thermal conductivity and surface emissivity are the two material properties required for a steady state thermal analysis of the nozzle/pressure vessel joint.

In order that maximum temperatures would be predicted, tolerances were applied to the thermal conductivity of both the aluminum and ARMCO and the resulting utilized lower values are shown in Tables 1 and 2 of Reference (c). Conductivities of the 7075-T73 aluminum and ARMCO 22-13-5 are also shown in References (d) and (e).

The ANSC Materials Group had previously estimated (Reference (c)) a value for the surface emissivity of ARMCO 22-13-5 to be 0.20 and for the uncoated 7075-T73 aluminum it was estimated to be 0.10. These values were used for the current analysis. However as previously noted in Reference (c), the emissivity of either material has a negligible effect on computed temperatures.

C. BOUNDARY CONDITIONS

1. <u>Convection</u>

The nominal convection boundary conductions used for this analysis are shown in Figure 1. The heat transfer coefficient distribution and coolant temperature distribution along the inside surface of the nozzle were taken from the results of "Normal End of Life" analysis 09SP015WLG. This regeneratively cooled nozzle analysis is a revision of 09SP005 which was reported in Reference (f). The heat transfer coefficients and fluid temperatures from this analysis are shown in Figures 5 and 6 of Reference (c).

Other convective heat transfer coefficients were calculated from Equation (4) of Reference (g). This equation is:

$$h = 0.023\ (k_b/D)\ (N_{RE})_b^{\ 0.8}\ (N_{PR})_b^{\ 0.4}\ C_1\ (T_w/T_b)^{-C_2} \tag{1}$$

where $C_1 = 1.0$ and $C_2 = 0.765$ for $T_w/T_b < 1.8$

$C_1 = 0.7$ and $C_2 = 0.20$ for $T_w/T_b \geq 1.8$

D = characteristic dimension

k = thermal conductivity

h = heat transfer coefficient

N_{RE} = Reynolds number

N_{PR} = Prandtl number

T_b = bulk fluid temperature (°R)

T_w = wall temperature (°R)

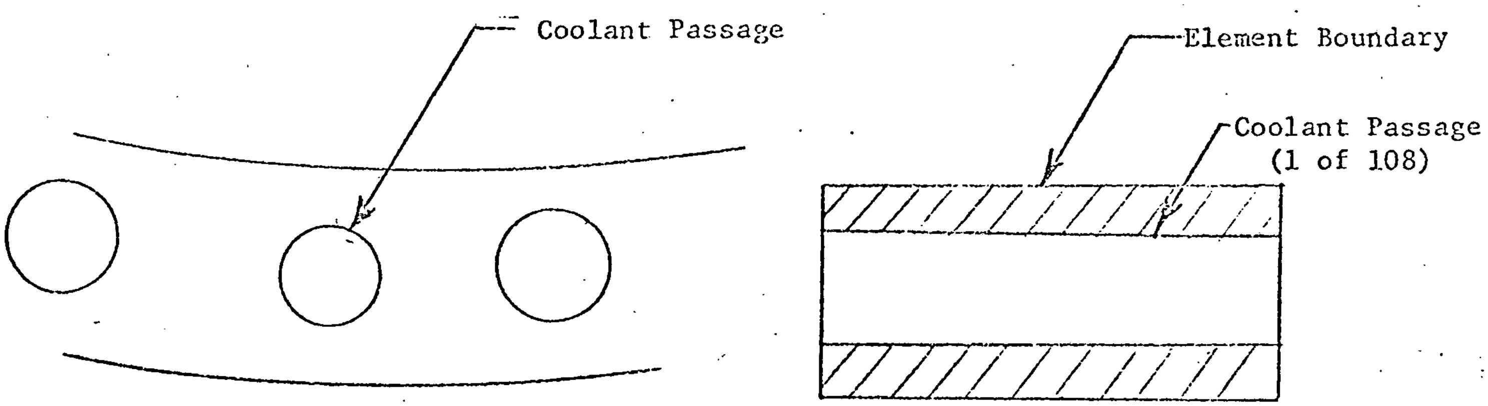
and the subscript b refers to properties evaluated at bulk fluid temperature. All fluid thermal properties were obtained from Reference (h) and are shown in Table 4 of Reference (c).

On the surface of the pressure vessel near the threaded end of the attachment bolts it was assumed that the entire plenum flow (approximately 76 lb/sec from the minimum flow rate listed in Enclosure (2) of Reference (i)) would be forced through a 3/4 inch wide gap to provide cooling. The resulting heat transfer coefficient computed from Equation (1) was approximately 1000 Btu/hr/ft^2/°F. Again this value was multiplied by 0.8 and the resulting boundary coefficient is shown in Figure 1. The heat transfer coefficient on the inside pressure vessel wall at the face of the reflector inlet was assumed to be 210 Btu/hr/ft^2/°F to be consistent with the entire plenum flow through a 3-1/4 inch wide gap. The variation between the two locations was assumed to be linear.

The heat transfer coefficient along the outside diameter of the nozzle barrel section (300 Btu/hr/ft^2/°F) corresponds to the entire nozzle

flow through a 2-1/2 inch wide gap. The temperature of the fluid in the plenum (-252°F) was obtained from Reference (i).

In the bolt coolant flow passages it was necessary to compute "average" two-dimensional temperatures that would account for the heat transfer to the coolant. This was accomplished by computing the temperature that satisfied an energy balance in each of the two-dimensional annular segments which were elements that included flow passages. A typical coolant flow element might appear as shown in the following sketch:



The energy balance used to determine internal energy gain/loss in elements that included coolant passages was:

$$q_e''' = [q_n''' V_s - (T_e - T_c) h_c A_c] / V_{total} \quad (2)$$

where:

A_c = coolant passage surface area contained in an axi-symmetric annular element

h_c = heat transfer coefficient between element surface and coolant (from Equation (1))

T_c = coolant temperature

T_e = element temperature

q_e''' = effective internal heat generation rate per unit volume of element

E

q_n''' = nuclear heating rate per unit volume of solid material

V_s = volume of solid material in each annular element

V_{total} = total volume in each annular element

The actual implementation of Equation (2) in the finite element program that was used to solve for steady state temperatures was accomplished in two steps. These were:

1. Specify a reduced nuclear heating rate because of the channel volume

$$q_{input}''' = q_n V_s/V_{total}$$

2. Specify a modified heat transfer coefficient along boundaries of elements through which coolant channels pass so that the heat transfer coefficient-surface area product is equal to $h_c A_c$. With the E12202 finite element code this is accomplished by using the following relationship to compute the input heat transfer coefficients:

$$h_{input} \text{ along channel elements} - h_c\, A_c/A_{element}$$

where $A_{element}$ is the surface area of a single element internally used by the computer code.

Use of an energy balance to define temperatures in regions that contain cooling passages result in values that are directly usable in two dimensional stress analyses. It is not necessary to analyze several cross sections and estimate the actual "average" temperatures appropriate for stress calculations. The procedure of analyzing several cross sections can result in the prediction of unrealistic temperature discontinuities across cooling passages whereas the current procedure permits energy transfer to occur. It is believed that the only way to more accurately define the temperature field in these regions is through the use of three-dimensional thermal analyses. However, the current stress analyses are two-dimensional and the additional effort

required to conduct a three-dimensional thermal analysis is not considered justified until there is a more definite requirement for such detailed temperatures.

2. Thermal Radiation

Thermal radiation was assumed to exist from all external nozzle and pressure vessel surfaces to an environment temperature of -453°F. As previously discussed, it was concluded from examination of temperature profiles that no significant increase in computed temperatures would result from neglecting thermal radiation because of the small amount of energy transfer by this mode during steady state operation.

3. Other Boundary Conditions

Adiabatic surfaces were assumed to exist at the positions on the thermal model corresponding to the ends of the pressure vessel and nozzle. This assumption is justified because the heat flow is essentially one-dimensional at these locations and there is negligible heat flow across the adiabatic surfaces. Subsequent analysis (not shown) indicated that temperatures in this area are extremely sensitive to the assumed boundary temperatures and these are not clearly defined in Reference (j). Fortuitously, the influence of the holes through which the coolant enters the plenum tends to thermally isolate this area from the rest of the nozzle. For this reason, it was possible to make the adiabatic surface assumption and correct temperatures at the interface zone based on the most current best estimate of actual structure/nozzle interface conditions.

D. NUCLEAR HEATING

All nuclear heating rates correspond to graphite core, specification extreme conditions. They are tabulated in Table 5 of Reference (c).

E. RESULTS

All steady state, nominal condition temperatures were computed using the finite element method described in Reference (k). Calculated temperatures for each node point were punched on cards and transmitted to the Stress Analysis Group.

An isotherm plot of the computed temperatures is shown in Figure 7.

It can be seen from the tabulations of Table 1 and the plot of Figure 10 that the maximum calculated joint temperature is 478°F in the initial contraction section of the nozzle. This is lower than the previously computed temperature of 722°F at the same location (Reference (c)). It will be seen that the principal reason for the decrease in maximum temperature was the reduction in nominal wall thickness from 0.88 inches to 0.65 inches in the current analysis.

IV. REFERENCES

(a) ANSC Drawing 1138000-D, "Nozzle to Pressure Vessel Joint"

(b) ANSC Memorandum N8500:M1433 to J. J. Williams from J. L. Watkins, "Thermal Analysis of ARNCO 22-13-5 Nozzle/PV Joint With Upgraded Material Properties", dated 2 December 1971

(c) ANSC Engineering Operations Report, "Steady State Thermal Analyses of the NERVA Nozzle/Pressure Vessel and Reflector Joint", J. J. Williams, 28 September 1971

(d) ANSC Materials Data Release DRM 12.01, 7075-T73 Aluminum, dated 7 December 1970

(e) ANSC Materials Data Release DRM 38.02, Alloy 22-13-5, dated 30 August 1971

(f) ANSC Memorandum, N8110:M1709, to R. H. Coppo from J. J. Williams, "Thermal Analysis of Nozzle Coolant Channels", dated 15 June 1971

(g) Williamson, K. D., Bartlit, J. R. and Thurston, R. S., "Studies of Forced Convection Heat Transfer to Cryogenic Fluids", Preprint 38C, Presented to the AIChE Symposium on Advances in Cryogenic Heat Transfer Liquid Vapor Phase Conversion and Two Phase Phenomena in Cryogenic Systems; Part II, Sixtieth Annual Meeting, New York, November 26-30, 1967

(h) Hall, W. J., McCarty, R. D. and Roder, H. M., "Computer Programs for Thermodynamic and Transport Properties of Hydrogen", NBS Report 9288, dated 18 August 1967

(i) ANSC Memorandum, N4110:0067, to A. D. Cornell from W. E. Stephens, "State Points for the 1137400/Revision E Reference Engine", dated 26 February 1971

(j) Report WANL-TME-2753, Data Item S-31, Table 8-35

(k) Nonsteady Temperature Analysis of a Two-Dimensional Body By the Finite Element Method - Program E12202, ANSC User's Manual, F. Yee, 18 February 1970

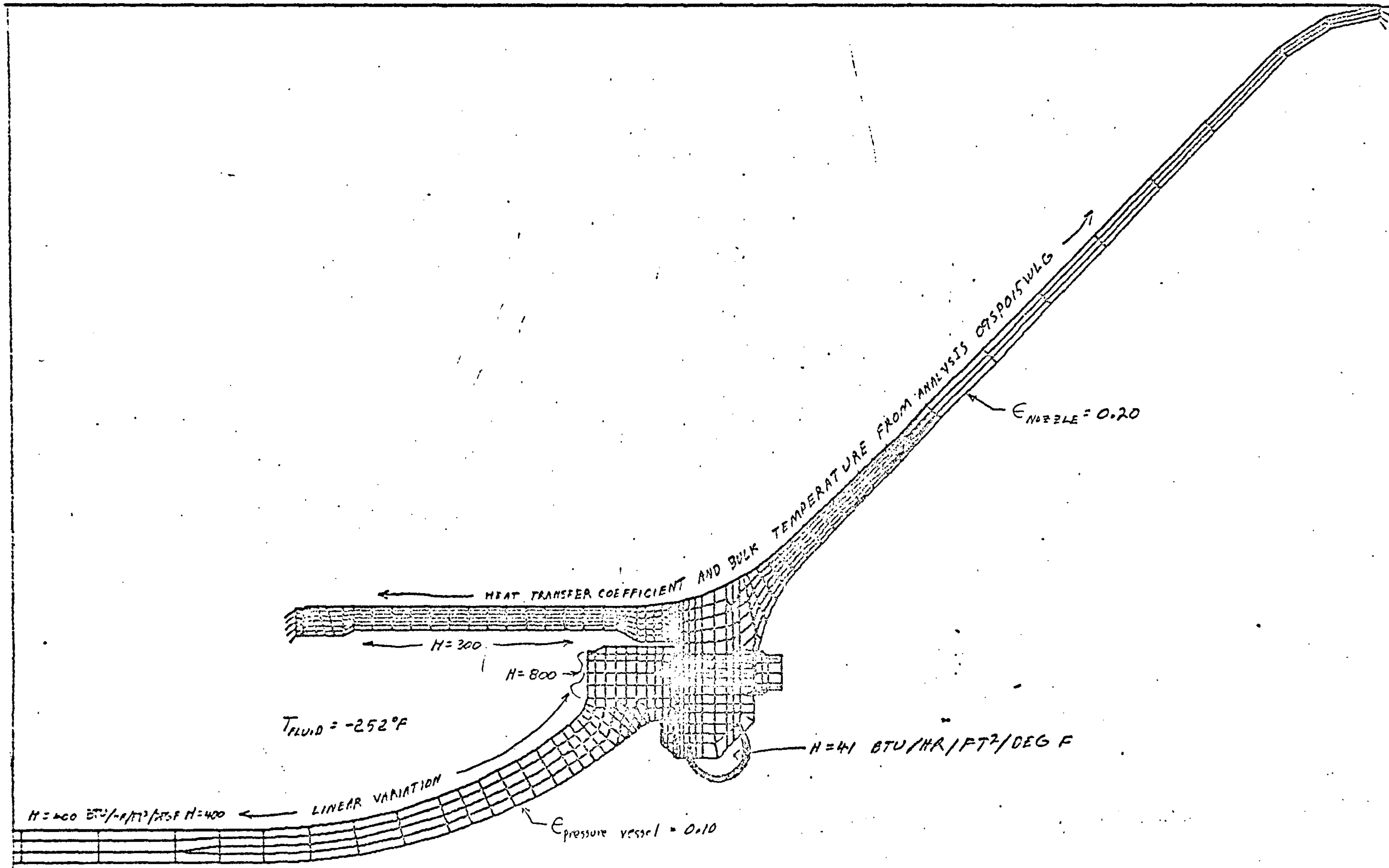


FIGURE 1 - BOUNDARY CONDITIONS

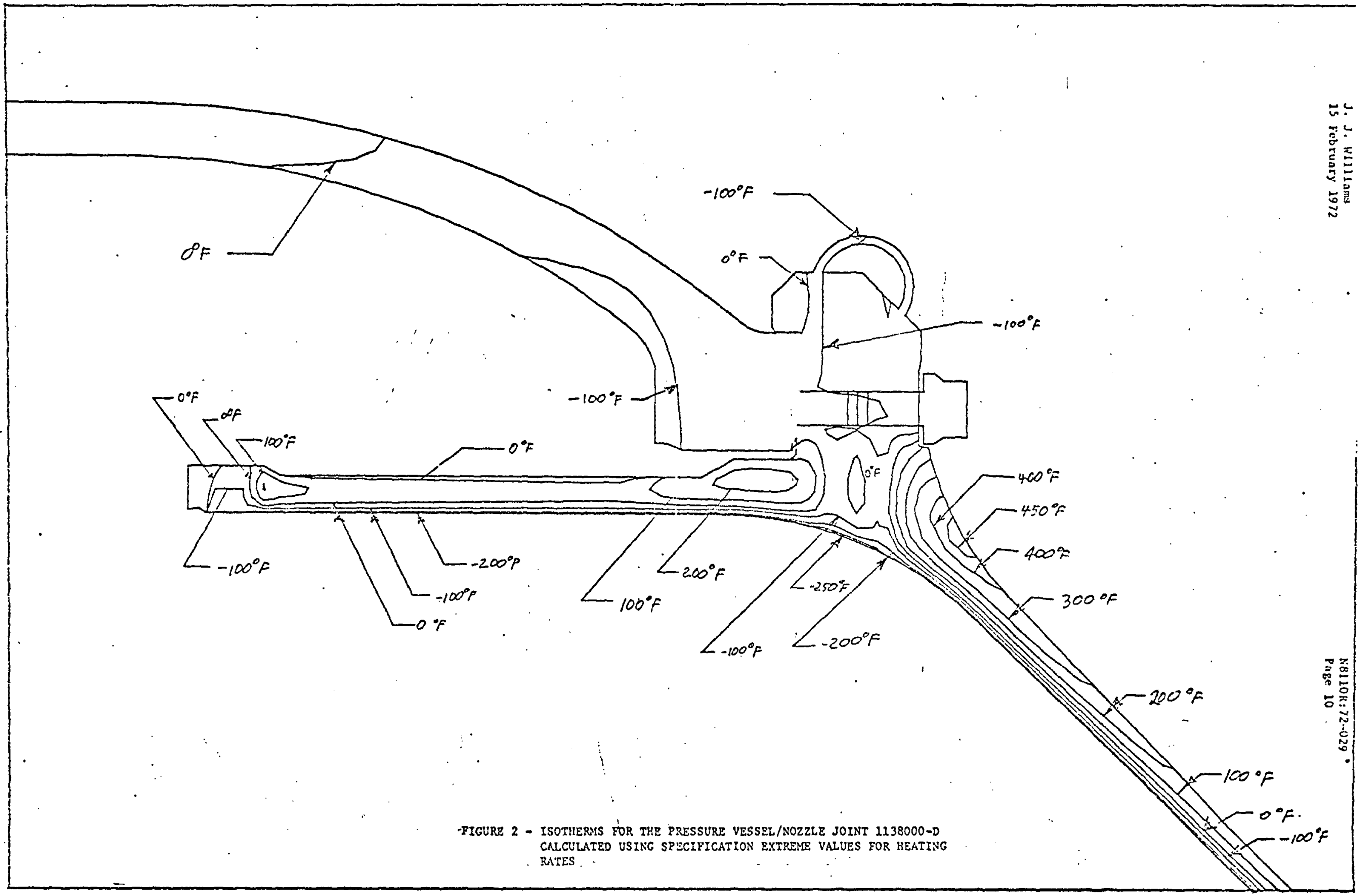


FIGURE 2 - ISOTHERMS FOR THE PRESSURE VESSEL/NOZZLE JOINT 1138000-D CALCULATED USING SPECIFICATION EXTREME VALUES FOR HEATING RATES

APPENDIX B

STRESS ANALYSIS OF NOZZLE/P.V. JOINT

2.0 INCH FLANGE

i

AEROJET NUCLEAR SYSTEMS COMPANY

SACRAMENTO, CALIFORNIA

TO: L. A. Shurley

10 March 1972
JLP:jm N8120R:72-026

FROM: U. A. Pineda

SUBJECT: Transmittal of Report N8120R:72-026 for Project 141

DISTRIBUTION: J. L. Pickering, K. Sato, J. G. Schumacher, J. L. Watkins

REFERENCE:

(a) Memo 4350 MM70-448 Enclosure (4, 11), H. W. Spaletta to J. L. Watkins, dtd. 22 December 1970, Subject: "ARMCO 22-13-5 Alloy Preliminary Screening Evaluation Results"

(b) Memo N8500:M1432, J. L. Watkins to J. L. Pickering, dtd. 30 November 1971, Subject: "Stress Analysis of ARMCO 22-13-5 Nozzle/PV Joint with Upgraded Material Properties"

ENCLOSURE:

(1) ANSC Report N8120R:72-026, "NERVA 75K Nozzle/Pressure Vessel Joint Stress Analysis Drawing No. 1138000-D", dtd. 10 March 1972

Enclosure (1) is the steady state stress and joint compatibility study in the ARMCO 22-13-5 Nozzle/Pressure Vessel Number 1138000-D.

U A Pineda

U. A. Pineda, Supervisor
Applied Mechanics Section
Engineering Staff Department

CLASSIFICATION CATEGORY
Unclassified
J. G. Schumacher 3/13/72
CLASSIFYING OFFICER DATE

ENCLOSURE (1)

N8120R:72-026

ENGINEERING OPERATIONS REPORT

NERVA 75K NOZZLE/PRESSURE VESSEL JOINT

STRESS ANALYSIS DRAWING NO. 1138000-D

PROJECT 141

10 MARCH 1972

J. L. PICKERING

J. L. Pickering

iii

APPROVED:

K Sato

K. SATO, MANAGER
ENGINEERING STAFF DEPARTMENT

CLASSIFICATION CATEGORY
Unclassified
J. W. Schumacher 3/13/72
CLASSIFYING OFFICER DATE

NERVA 75K NOZZLE/PRESSURE VESSEL JOINT STRESS ANALYSIS DRAWING NO. 1138000-D

I. INTRODUCTION

This report presents the joint compatibility and stress analysis of the nozzle/pressure vessel Concept 1138000-D. This concept differs from that used in Report N8120R:71-005 as a result of replacing the two seal grooves at the nozzle/pressure vessel interface with one seal groove (changing the radial location of the shear lip and thus the pressure vessel configuration) and using higher material allowables for ARMCO 22-13-5 based on a more realistic assessment of the material data. A geometrical and material comparison between the two nozzle configuration relates

Dwg. No. 1139587	Dwg. No. 1138000-D
$R_{shear\ up} = 24.727''$	$R_{shear\ lip} = 24.350''$
$t_{flange} = 2.4$	$t_{flange} = 2.0$
$t_{nozzle\ shell} = .88$ (tangent loc.)	$t_{nozzle\ shell} = .65$ (tangent loc.)
ARMCO 22-13-5 (Ref. 1)	ARMCO 22-13-5 (Ref. 2)
$F_{TY_{RT}} = 40500$ psi	$F_{TY_{RT}} = 47000$ psi

A thermal stress analysis was also performed using a pseudo steady state operating condition. That is, tolerances were applied to thermal conductivities and heat transfer coefficients so that maximum temperatures would be predicted for steady state, normal flight operating condition. In addition, specification extreme values were used for nuclear heating rates. As was stated, the temperatures developed are assumed to be a maximum. However, this approach does not necessarily give the maximum thermal gradients which dictates the magnitude of the thermal stresses. The thermal stresses were developed using the temperatures and

are assumed to be a maximum condition, with consideration of the previous statement.

II. SUMMARY/CONCLUSIONS

The results in the form of margin of safety values are listed in Table I. All developed margins were positive except for the pressure vessel hoop membrane stress. This negative margin was a result of a change in the coolant coefficient from that used in the thermal analysis in Report N8120R:71-005 which increased the mean wall temperature in the cylindrical portion by approximately 100°. Therefore, this negative margin is a thermal problem and can be corrected by sizing the wall when the correct wall temperature is established.

The over-all compatibility and stresses developed indicate that the nozzle configuration analyzed in this report can perform adequately under the steady state operating condition imposed in this analysis. The buckling analysis of the core support was not performed in this report because of the similarity of the loading and geometry of the core support analyzed in Report N8120R:71-005 which indicated a good margin against buckling.

III. TECHNICAL DISCUSSION

The nozzle/pressure vessel configuration analyzed in this report was performed with the finite element program. The information used in this report was taken from the Appendix A (Analysis No. AM-NA-0024) which is the detailed stress analysis of the nozzle/pressure vessel joint.

The assumption made in this analysis was that the rotation and radial deflection of the core support at the reflector cylinder interface developed in Report N8120R:71-005 can be used as boundary conditions for the configuration used in this report. The results of this report indicate that this assumption was good and that a small error in stress magnitude, if any, was the result.

TABLE I - MARGIN OF SAFETY VALUES

Page Analysis #AM-NA-0024	Part (Location)	Stress	Type	M.S.	Condition
	NOZZLE FLANGE				
F.E.M. Printout	Shear Up	σ_z 35000	Peak Notch Effect	High	Hydro
6	Bolt Area	σ_R 30000	Primary + Bending	$T_{RT} = 70°$, +.67	Hydro
24	Bolt	$\sigma_{axial} = 89610$	Primary	$T_{RT} = 70$, +.5	Hydro
24		$\sigma_{axial} = 134000$	Primary	T_{-235}, +.17	S.S. (Steady State)
	NOZZLE SHELL				
9	Max Stress Location	$\sigma_{hoop} = 29300$	Primary	$T_{165°F}$, +.22	S.S.
9	Section A-A	$\varepsilon_{eff} = .0043$ (inside surface)	Peak	Need Mat'l Data (Low-cycle Fatigue)	S.S.
10	Max Stress Location	$\sigma_{meridional} = 28000$	Primary + Bending	$T_{450°F}$, +0.25	S.S.
	PRESSURE VESSEL				
11	Max Stress Location	$\sigma_{hoop} = 41400$	Primary	$T_{70°}$, -.025	S.S.
12	Max Stress Location	$\sigma_{meridional} = 28000$	Primary + Bending	$T_{-30°F}$, +0.897	S.S.

TABLE I - MARGIN OF SAFETY VALUES (Cont.)

Page Analysis #AM-NA-0024	Part (Location)	Stress	Type	M.S.	Condition
	CORE SUPPORT				
13	Max Stress Location	$\sigma_{hoop} = 33500$	Primary	$T_{50°F}$, +0.22	S.S.
14	Max Stress Location	$\sigma_{meridional} = -23000$	Primary + Bending	$T_{70°F}$, +1.174	S.S.

APPENDIX I

NOZZLE/PRESSURE VESSEL NUMBER 1138000-D

JOINT STRESS ANALYSIS

ANALYSIS NO. AM-NA-0024

i

F

AEROJET NUCLEAR SYSTEMS COMPANY
SACRAMENTO, CALIFORNIA

APPLIED MECHANICS SECTION
N8120

ANALYSIS NO. AM- NA-0024

DATE 10 March 1972

SUMMARY OF ANALYSIS

Project 141 System/Component Nozzle

Part Nozzle/Pressure Vessel Drawing No. 1138000-D

Subject Nozzle/Pressure Vessel Number 1138000-D Joint Stress Analysis

Reference(s)

Distribution:
L. A. Shurley
J. L. Pickering
K. Sato
J. G. Schumacher
J. L. Watkins

*Summary Sheet Only
File: AM- 1200-300

Engineer J. L. Pickering — J. L. Pickering Approved J. G. Schumacher — J. G. Schumacher

OBJECTIVE: To determine margin-of-safety values for the selected design under the operating steady state condition.

ASSUMPTIONS: That the maximum loading condition (maximum pressures and deltas) when used in the analysis will provide the minimum margins when compared to the allowables at temperature based on the maximum heating rates and/or the extreme environmental conditions.

REFERENCES (Analysis Methods):

See Enclosures

RESULTS AND CONCLUSIONS: The over-all compatibility and stresses developed indicate that the nozzle configuration analyzed in this report can perform adequately under the steady state operating condition imposed in this analysis.

RECOMMENDATIONS AND COMMENTS: The reflector cylinder was not included in the finite element model used in this report; instead, the rotation and radial deflection of the core support in Report N8120R:71-005 was used as boundary condition, with satisfactory results.

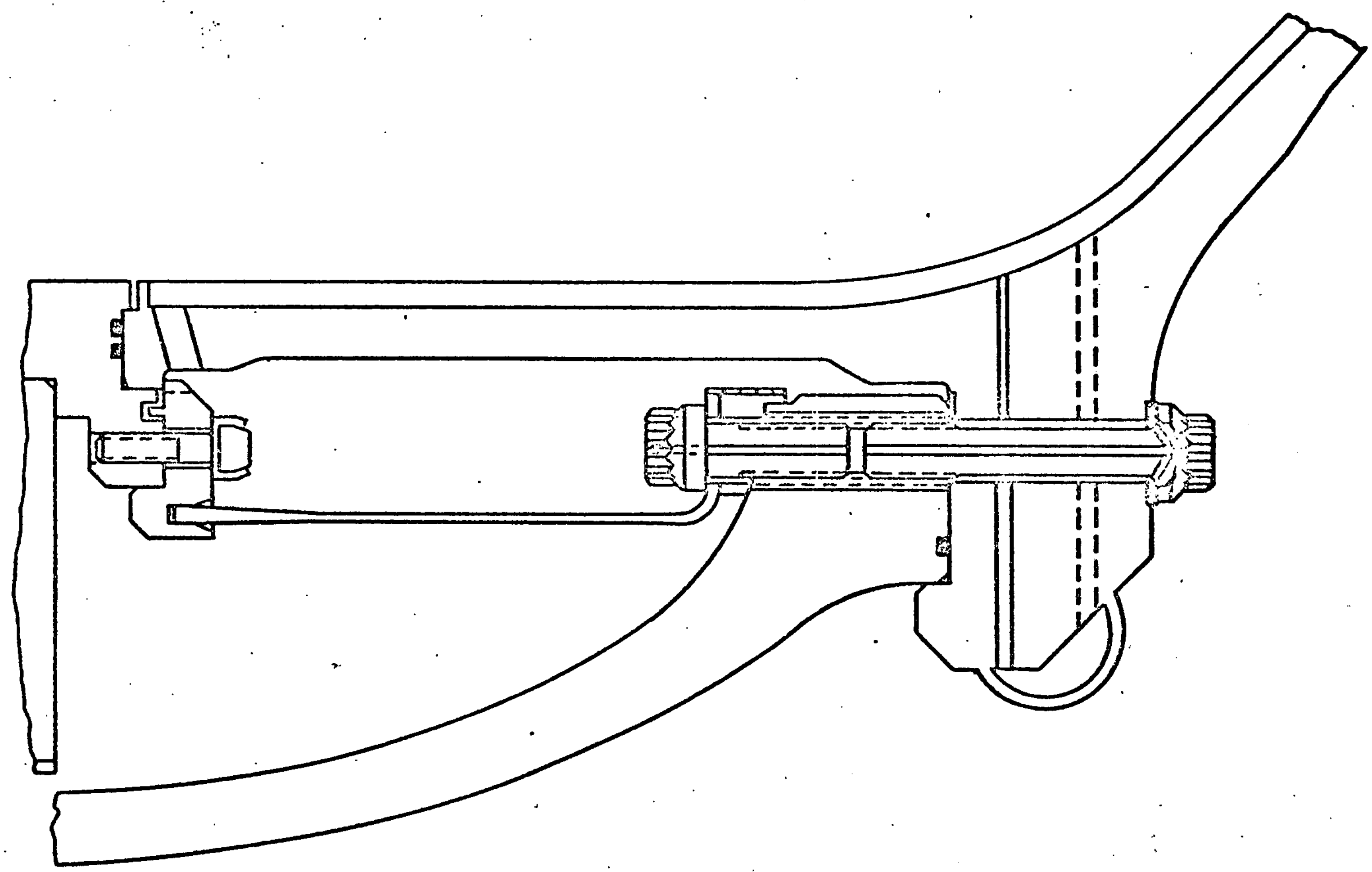
TABLE OF CONTENTS

REFERENCES

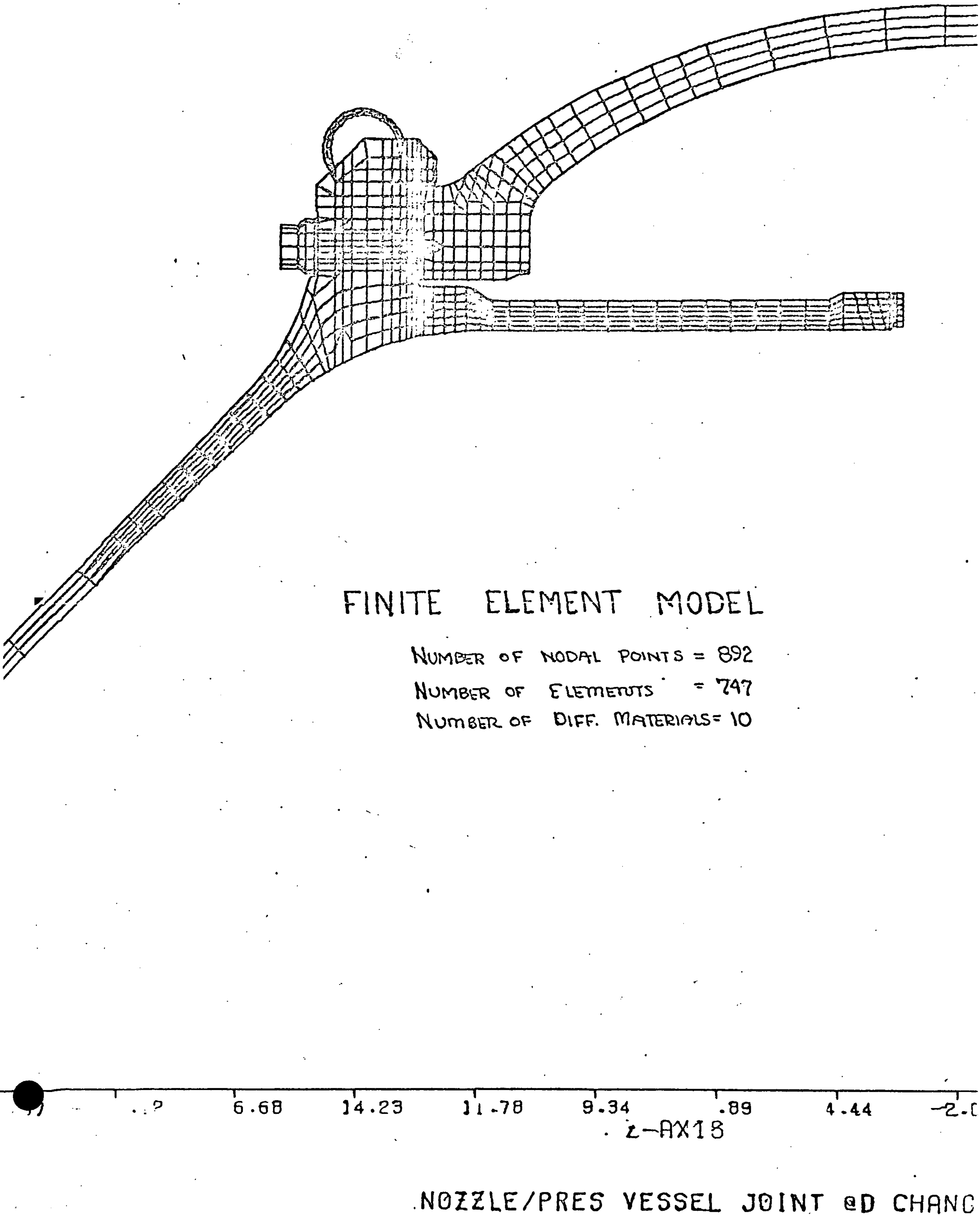
1. Memorandum N8500:M1298, J. L. Watkins to J. L. Pickering, Dated 25 May 1971, Subject: "Stress Analysis of ARMCO 22-13-5 Nozzle/PV Joint"

2. Memorandum N8120:097, U. A. Pineda to L. A. Shurley, Dated 19 November 1971, Subject: "Report N8120R:71-005 Rev. A, 'NERVA 75K Nozzle/Pressure Vessel and Nozzle/Reflector Joint Stress Analysis'", for Project 141

3. Memorandum N8110R:72-029, O. J. Demuth to L. A. Shurley, Dated 15 February 1972, Subject: "Steady State Temperatures for the NERVA Nozzle/Pressure Vessel and Reflector Joint Number 1138000-D Using Specification Extreme Values for Nuclear Heating Rates"



AEROJET NUCLEAR SYSTEMS COMPANY


FINITE ELEMENT MODEL
NUMBER OF NODAL POINTS = 892
NUMBER OF ELEMETNTS = 747
NUMBER OF DIFF. MATERIALS = 10
6.68
14.23
11.78
9.34
.89
4.44
Z-AXIS
NOZZLE/PRES VESSEL JOINT @D CHANG

SUBJECT
BY JLP
CHK. BY
DATE

LOADING CONDITIONS:

ASSUMED: MAX STRESS CONDITION

(MIN) $P_c = 446$
(MAX) $P_{RI} = 1245$
(MAX) $P_{ESO} = 1176$

DESIGN NORMAL END OF LIFE (REF. 1)

CORE SUPPORT $\Delta P \approx 800$

CORE LOAD

REF. 1 --- , $F_{MAX} = 2320 P_{ESO}(max) - 1553 P_c(min) - 747 \{P_{RI}(max) - 6$

$= 1,110,150$ LBS

"NO PRE-LOAD INCLUDED"

NOTE: THE VARIANCE IN THE CHAMBER PRESSURE IS SMALL:

	MIN	NOM	MAX
P_c	446	450	455

THEREFORE: THE FOLLOWING PRESSURES WILL BE USED.

$P_c = 455$

$P_{RI} = 1245$

$P_{ESO} = 1176$

$F_{CORE} = 1,110,150$ LBS

MODEL INPUT

PRESSURE DISTRIBUTION AS SHOWN IN FIGURE 1

$$P_{c\,(MAX)} = 455$$

CORE LOADING

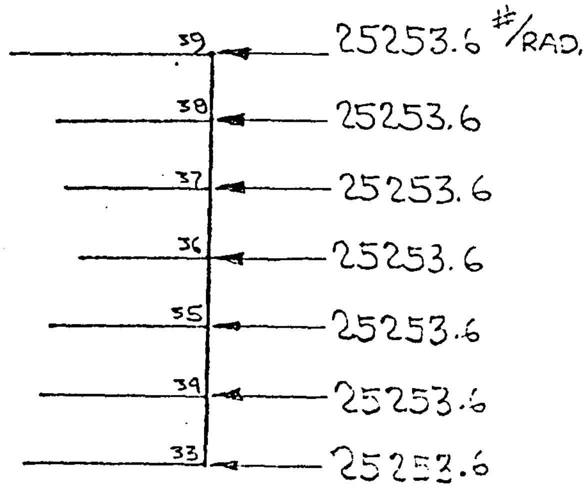
$$F_{MAX} = 1{,}110{,}150 \text{ LBS}$$

IN THE F.E.M. ALL LOADS ARE CONSIDERED AS TOTAL FORCES ACTING ON ONE RADIAN SEGMENT.

$$\therefore F_{MAX}/\text{RAD.} = \frac{1110150}{2\pi}$$

$$= 176775.5 \text{ LBS/RAD.}$$

INPUT AT FORWARD END OF CORE SUPPORT:



SUBJECT

DATE 2/29/72

WORK ORDER

BY JLP

CHK. BY

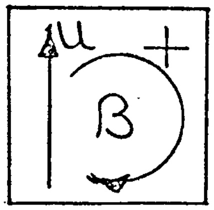
DATE

ROTATION & DEFLECTION OF FLANGES

THE FOLLOWING VALUES REPRESENT AN AVERAGE VALUE OF BOTH ROTATION AND DEFLECTION OF THE CENTER OF GRAVITY OF BOTH RINGS.

ITEM	MECH. LOAD	THER + MECH 1ST ITERATION	THER + MECH* 4th ITERATION	DESCRIPTION
UNF	.011	.0197	.0179	RADIAL DEFLECTION OF NOZZLE FLANGE
UVF	.0078	.0037	.0027	RADIAL DEFLECTION OF PRESSURE VESSEL FLANGE
BNF	.0032	.0098	.0097	ROTATION OF NOZZLE FLANGE
BVF	.0029	.008	.0076	ROTATION OF PRESSURE VESSEL FLANGE

SIGN CONVENTION



* BOLT LOAD RELAXED BECAUSE OF YIELDING IN WASHER UNDER BOLT HEAD (SHOULD HAVE PROVIDED HIGHER MAT'L ALLOWABLES IN THE FICTICIOUS MATERIAL). THE LACK OF PRE-LOAD APPARENTLY DID NOT EFFECT THE OVERALL JOINT COMPATIBILIT

AGCS-0800-11

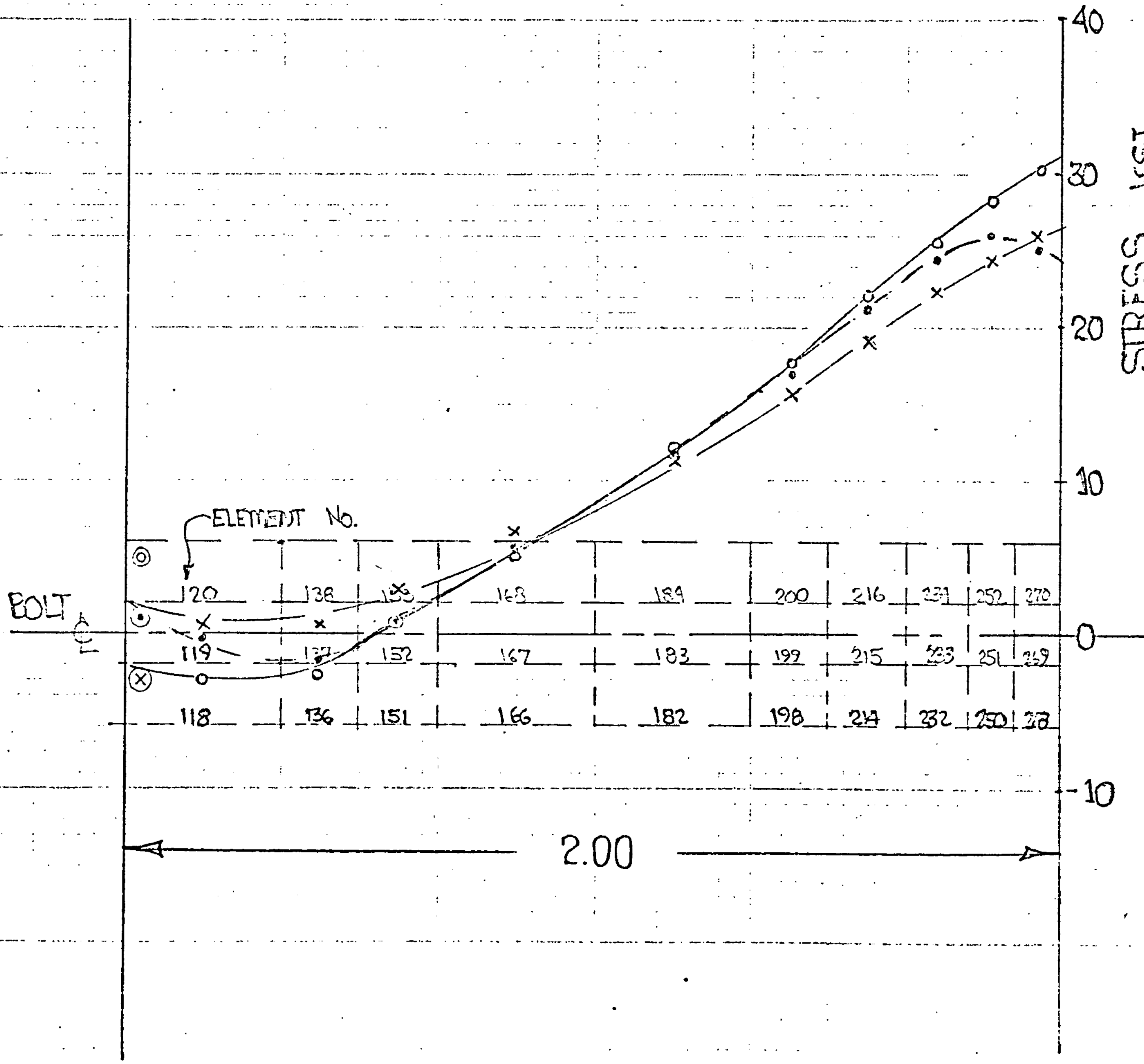
SUBJECT		REPORT NO.	PAGE 6 OF
			DATE 2/28/72
			WORK ORDER
BY JLP	CHK. BY		DATE

NOZZLE FLANGE BOLT HOLE AREA

RADIAL STRESS σ_R

MECH. LOADS ONLY (WITH TEMPERATURE, WITHOUT α'S)

A POSSIBLE LOADING CONDITION AT START-UP

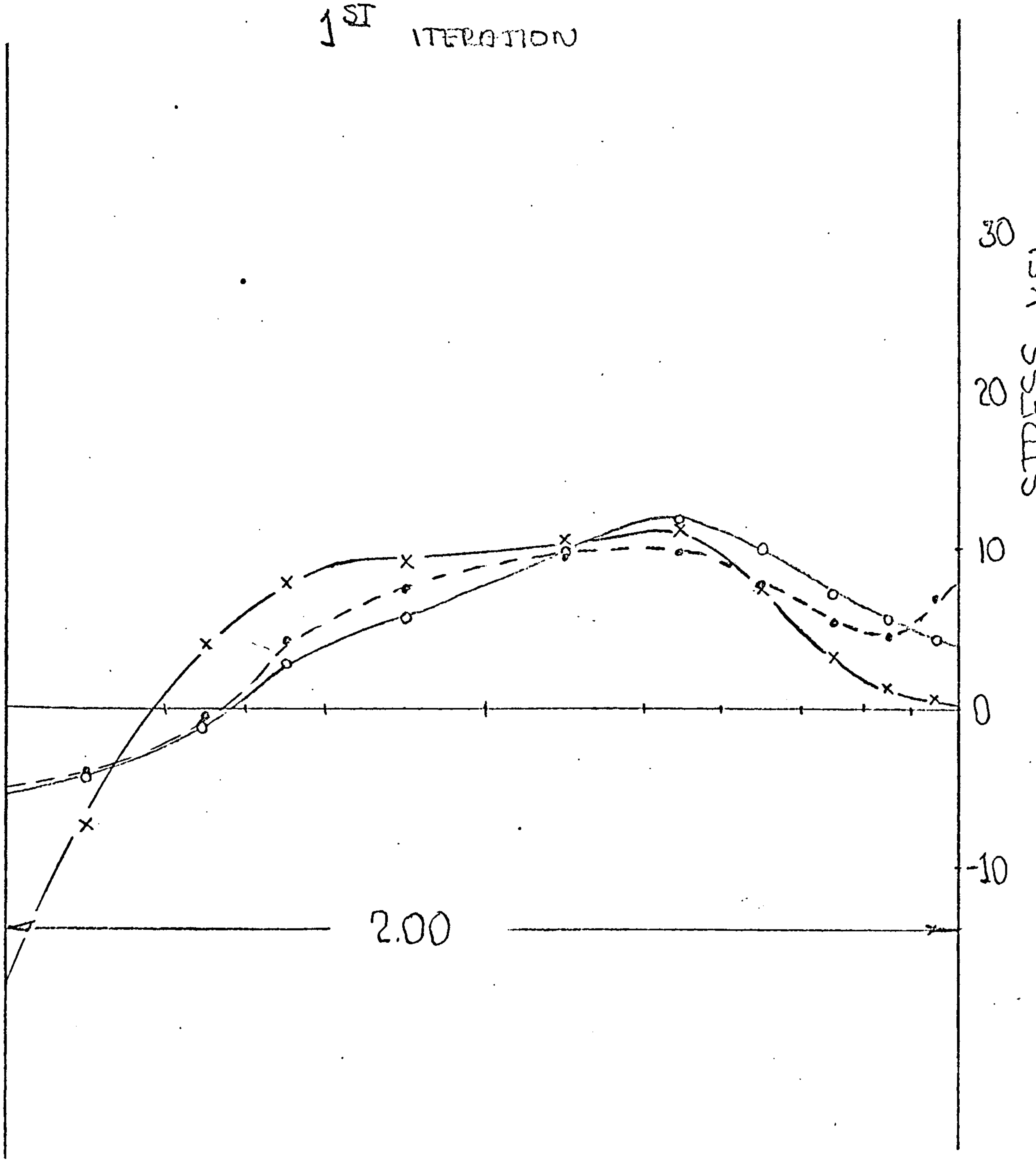


NOZZLE FLANGE BOLT HOLE AREA

RADIAL STRESS σ_R

MECH + THERMAL STRESS (STEADY STATE)

1^{ST} ITERATION



AGCS-0800-11	REPORT NO.	PAGE 8 OF
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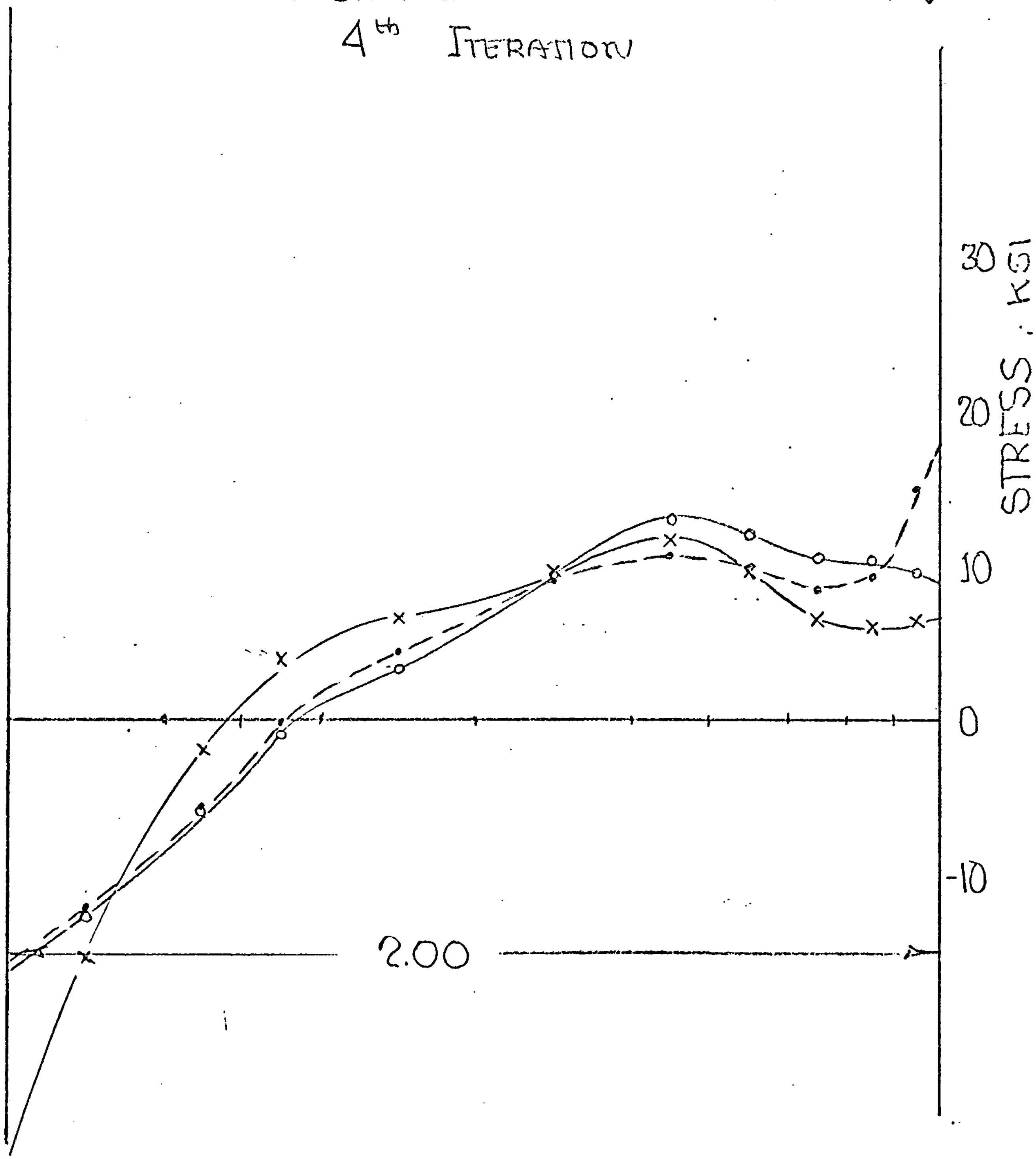
BY JLP	CHK. BY	DATE

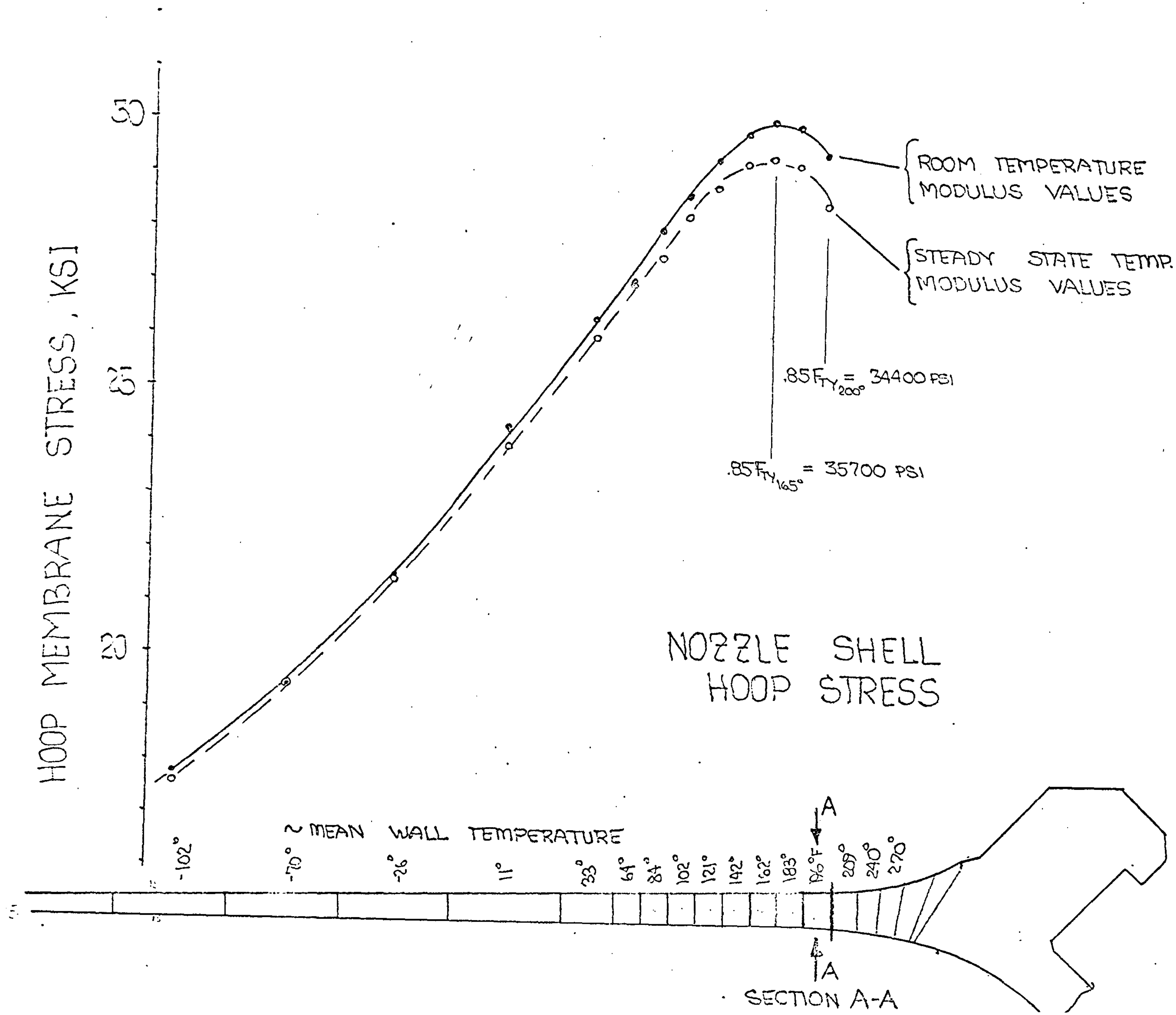
NOZZLE FLANGE BOLT HOLE AREA

RADIAL STRESS σ_R

MECH + THERMAL STRESS (STEADY STATE)

4th ITERATION





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SUBJECT

BY JLP

CHK. BY

DATE

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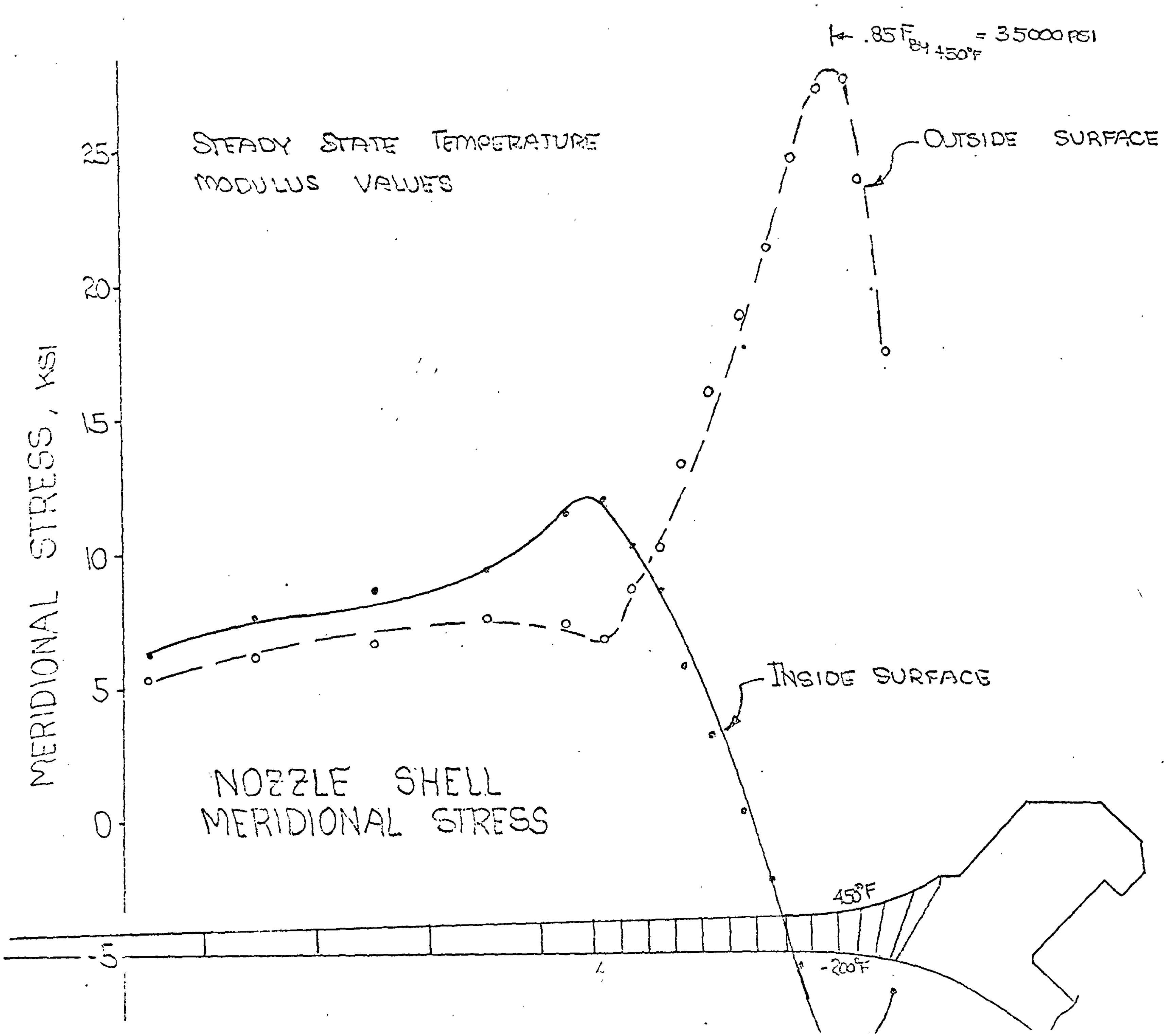
WORK ORDER



AGCS-0800-14

SUBJECT

BY JLP

CHK BY

DATE

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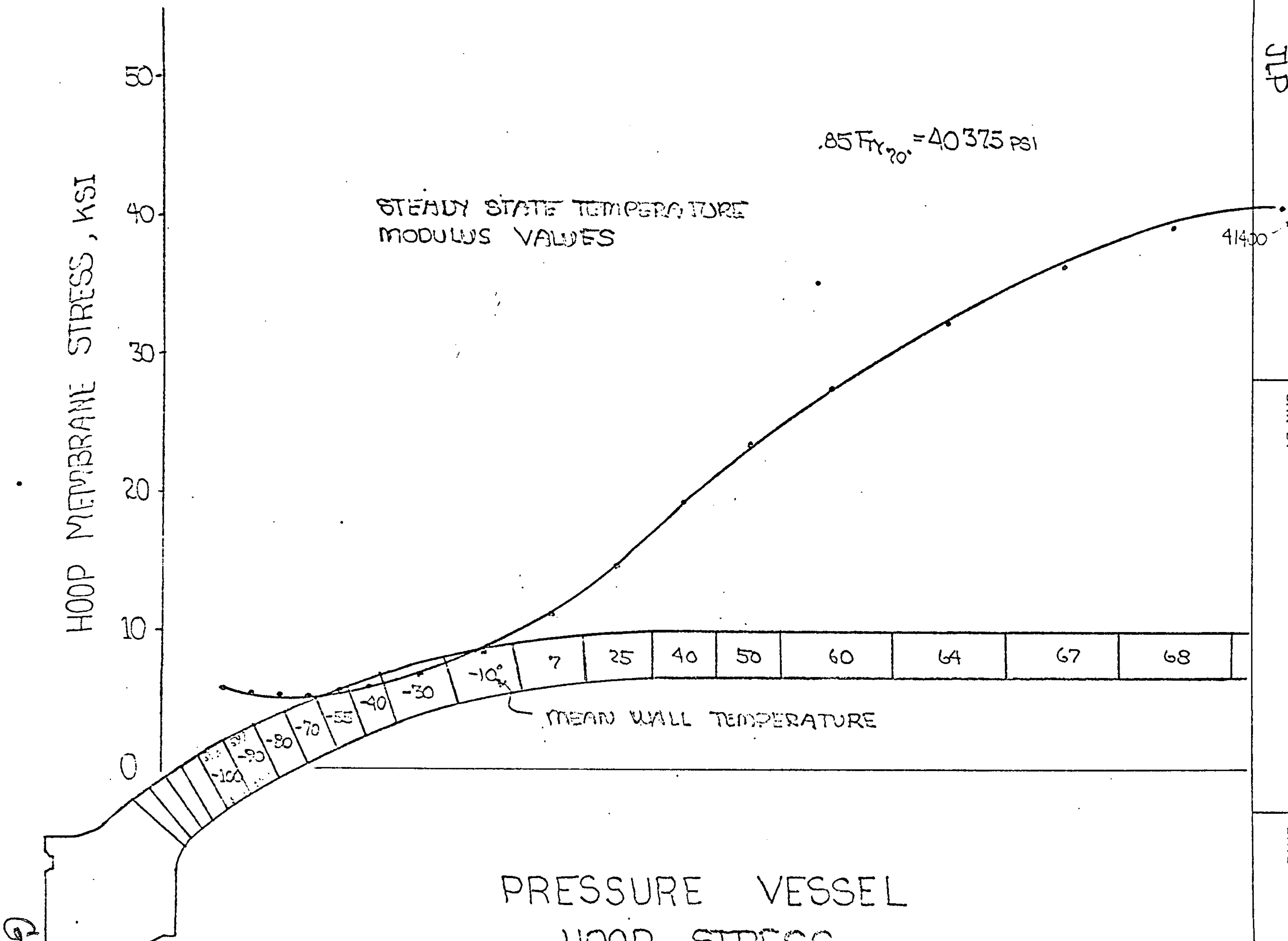

PRESSURE VESSEL
HOOP STRESS

AGCS-0000-11

SUBJECT

BY JLP

CHK BY

DATE

WORK ORDER

DATE 2/24/72

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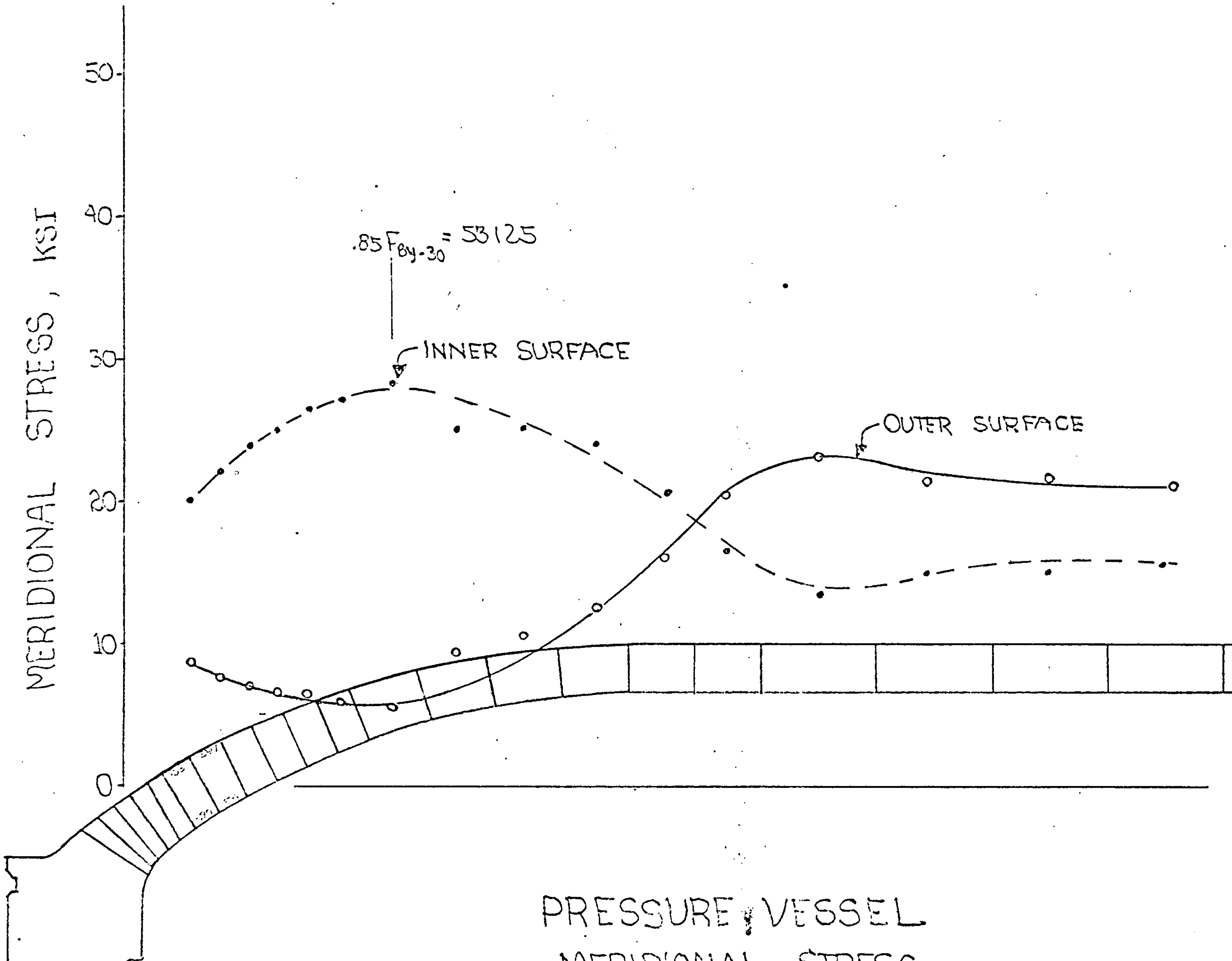

PRESSURE VESSEL
MERIDIONAL STRESS

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SUBJECT

BY JLP

CHK. BY

DATE

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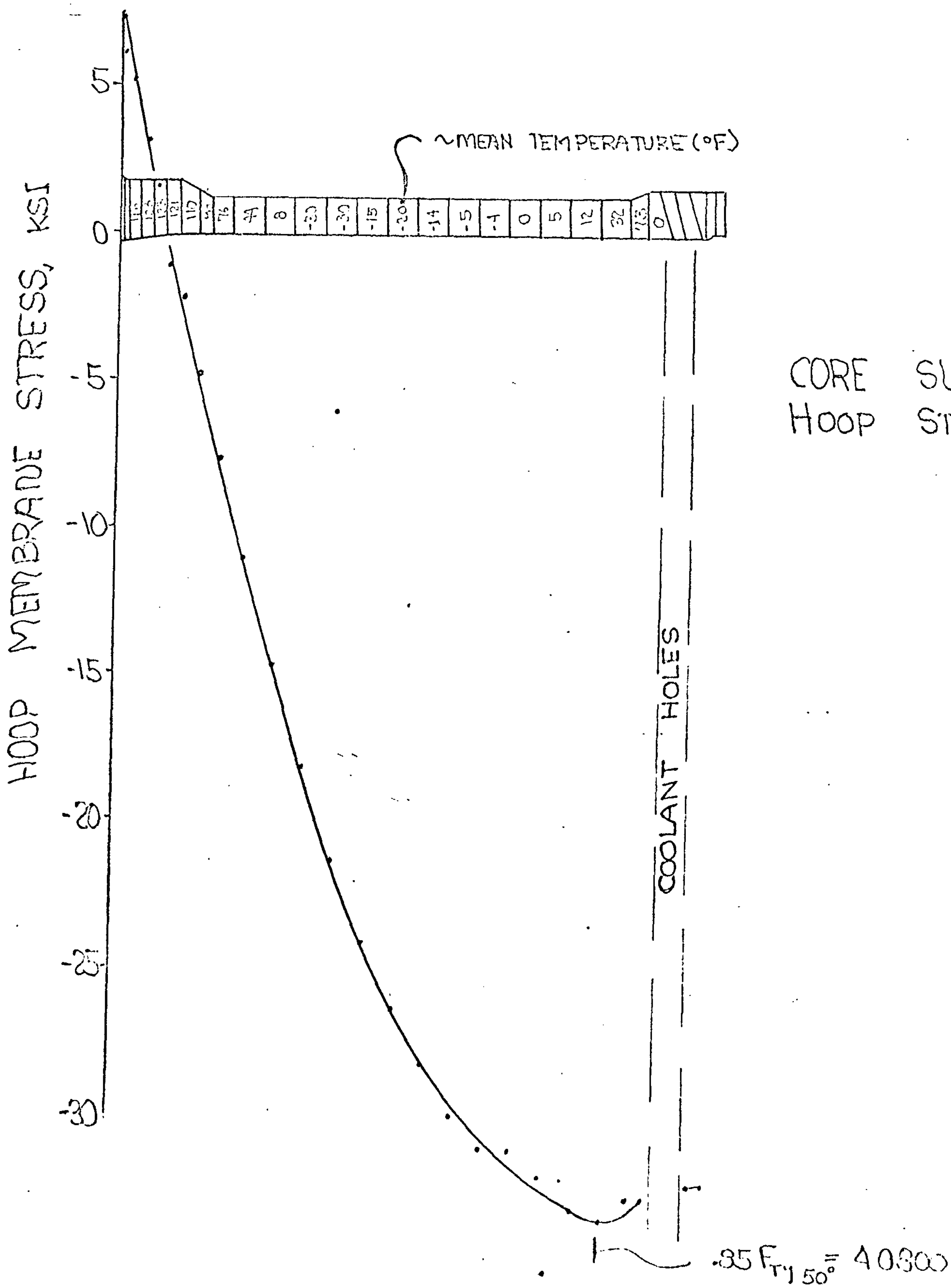
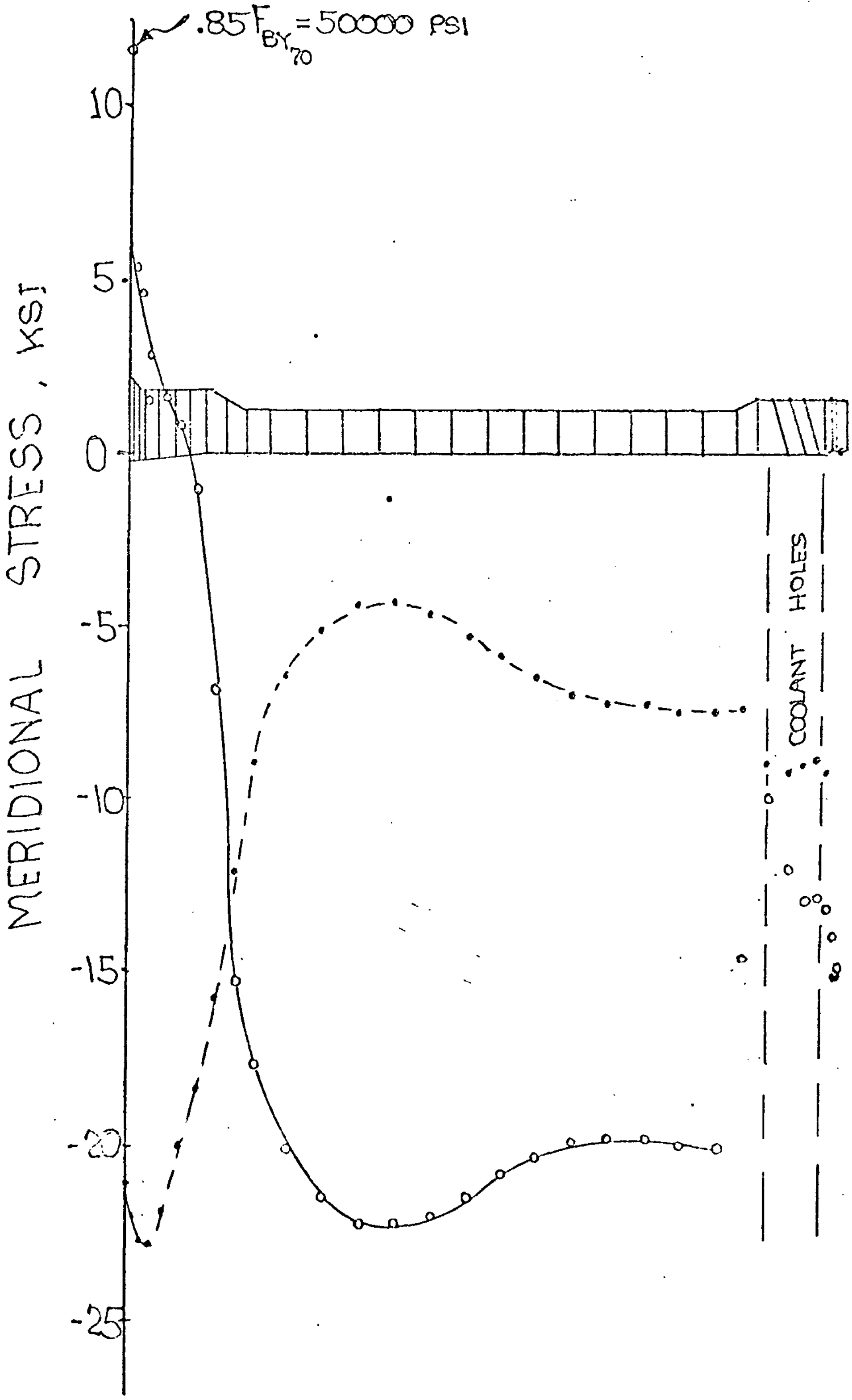
BY JLP	CHK. BY	DATE



CORE SUPPORT
HOOP STRESS



CORE SUPPORT
MERIDIONAL STRESS

SUMMARY OF INTERFACE REACTIONS

THE FOLLOWING PAGES RELATE THE METHOD USED IN DEVELOPING THE LOADS AT THE INTERFACE OF THE NOZZLE AND PRESSURE VESSEL FLANGES. A SUMMARY OF THOSE CALCULATIONS ARE PRESENTED IN TABULAR FORM:

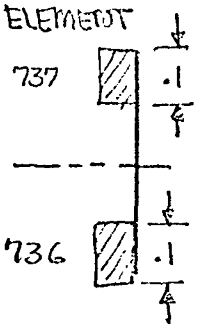
ITEM	MECH ONLY	STEADY STATE THER. + MECH 1ST ITERATION	STEADY STATE THER + MECH* 4th ITERATION
BOLT PRELOAD (WASHER LOAD)	2585133 LBS	2587643 LBS	2048660 LBS
INTERFACE MOMENT	-530 IN-LB/IN (OPENING MOMENT)	2947 IN-LB/IN	4465 IN-LB/IN
SHEAR UP	10206 LB/IN	9500 LB/IN	9879 LB/IN

* BOLT LOAD RELAXED BECAUSE OF YIELDING IN WASHER UNDER BOLT HEAD (SHOULD HAVE PROVIDED HIGHER MAT'L STRENGTH IN THE FICTICIOUS MATERIAL). THE LACK OF PRELOAD APPARENTLY DID NOT EFFECT THE OVERALL JOINT COMPATIBILITY, HOWEVER, DID EFFECT THE INTERFACE LOADS. THE LOADS DEVELOPED BY THE FIRST ITERATION WILL BE USED IN BOLT LOAD.

INTERFACE REACTIONS

MECH. ONLY (WITH TEMPS / WITHOUT α'S)

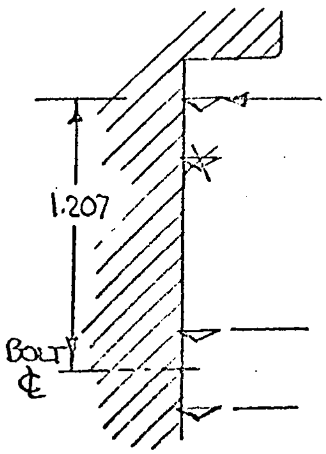
BOLT HEAD (WASHER)



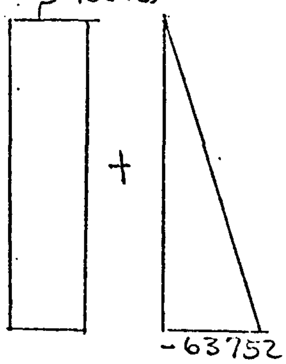
ELEMENT		σ_z	$F_z = (t)(\sigma_z)$	$F_{TOTAL} = 2\pi r F_z$
737	.1	-76200	-7620	-1132217
736	.1	-102370	-10237	-1452917

$F_{TOTAL} = \underline{2585133 \text{ LBS}}$

INTERFACE MOMENT



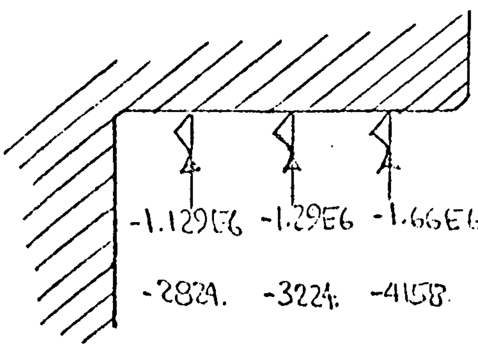
$\sigma_{z\ TRIANGLE}$	$F_z = \frac{1}{2}\left(\frac{2\pi r h}{2\pi r}\right)\sigma_{z\ TRIANGLE}$		$F_{TOTAL} = 2\pi r F_z$
-277170	-693		-105929
-534450	-1336	-1168 (AVERAGE)	-169681
-400230	-1006		



$\therefore$ MOMENT $= (1.207)(63752)/2\pi(23.133)$

$= -\underline{530}\ ^{IN\text{-}LB}/_{IN}$

SHEAR LIP



-1.129E6	-1.29E6	-1.66E6	σ_R
-2824.	-3224.	-4158.	$F_R = \frac{1}{2}\left(\frac{2\pi r h}{2\pi r}\right)\sigma_{R\ TRIANGLE}$

$F_{TOTAL} = -2824 - 3224 - 4158$

$= \underline{10206\ ^{\#}/_{IN} @ 24.34''R}$

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INTERFACE REACTIONS

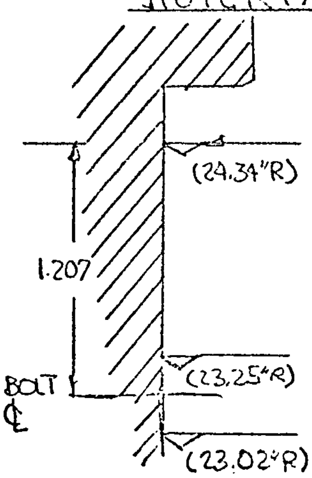
MECH. + THERMAL (1ST ITERATION)

BOLT HEAD (WASHER)

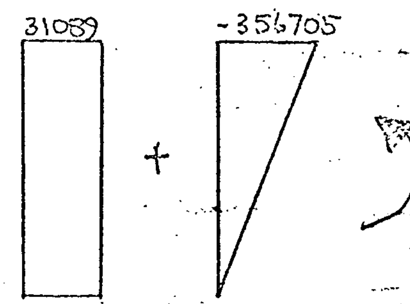
		σ_z	F_z	F_{TOTAL}
737 (23.66"R)	.1	-77754	-7775.4	-1155306
736 (22.60"R)	.1	-100920	-10092	-1432337

$F_{TOTAL} = 2587643$ LBS

INTERFACE MOMENT

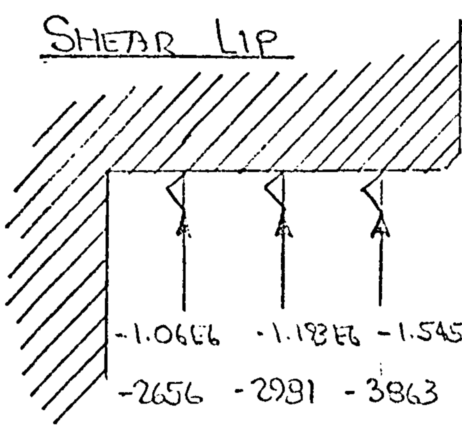


	σ_z	F_z		F_{TOTAL}
(24.34"R)	-1014800	-2537		-387794
(23.25"R)	-402020	-1005	-214 #/IN (AVERAGE)	-31089
(23.02"R)	+230700	577		



$$\text{MOMENT} = (1.207)(356705)/2\pi\,(23.133) = \underline{\underline{2947 \tfrac{\text{IN-LB}}{\text{IN}}}}$$

SHEAR LIP



σ_z	-1.06E6	-1.18E6	-1.545E6
F_z	-2656	-2981	-3863

$F_{TOTAL} = -2656 - 2981 - 3863$

$= \underline{\underline{-9500}}$ IN-LB/IN

INTERFACE REACTIONS

MECH. + THERMAL (4th ITERATION)

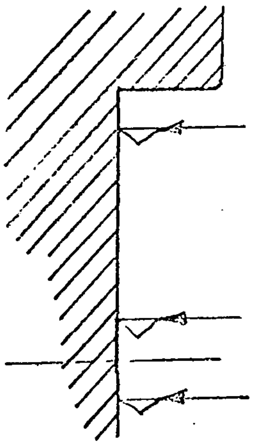
BOLT HEAD (WASHER)

	σ_z	F_z	F_{TOTAL}
23.66"R	-64920	-6492.	-964613.
22.60"R	-76383	-7638.	-1084046

$F_{TOTAL} = \underline{2048660 \text{ LBS.}}$

BOLT LOAD RELAXED BECAUS OF WASHER YIELDING

INTERFACE MOMENT



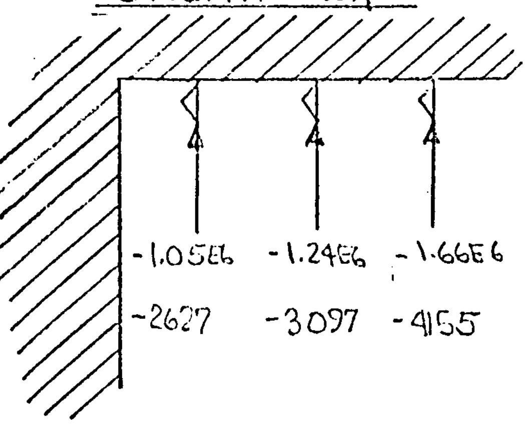
σ_z	F_z	F_{TOTAL}
-888740	-2222	-339629
148440	371	54120
961800	2405	347608

54120 + 347608 → ~~200889~~ TENSION

$M = (1.2)(-339629 - 200889$
$= .648622$ IN-LB
$= \dfrac{648622}{2\pi\ (23.133)}$
$= \underline{4465 \ \frac{\text{IN-LB}}{\text{IN}}}$

THE MOMENT VALUE DEVELOPED HAS NO REAL VALUE BECAUSE OF THE LOSS OF PRELOAD.

SHEAR LIP



-1.05E6	-1.24E6	-1.66E6	σ_R
-2627	-3097	-4155	F_R

$F_{TOTAL} = -2627 - 3097 - 4155$
$= \underline{9879 \ \#/\text{IN}}$

BOLT LOAD

THE AXIAL LOAD WILL BE DEVELOPED BY THE USE OF THE EQUILIBRIUM EQUATIONS

$$\therefore F_{BOLT} = \Sigma F_{AXIAL\ LOAD}$$

$$F_{CORE\ LOAD} = 1\,110\,150 \text{ LBS}$$

PRESSURE LOADING

$$F_{AXIAL} = F_{NOZZLE\ SHELL} + F_{FLANGE\ BOTTOM} + F_{FLANGE\ TO\ SHELL}$$

$$= (4094.4)(2\pi)(20.923) + \pi(21.42^2 - 20.9^2)(455) + \pi(24.16^2 - 22.32^2)(1245)$$

$$= 537989. + 61060 + 333768$$

$$= 932\,820 \text{ LBS}^*$$

* THIS VALUE IS BASED ON THE OLD GEOMETRY REF 2.

$$\Sigma F_{AXIAL} = \Sigma F_{PRESS} + F_{EXT\ LOAD}$$

$$= 932820 + 1110150$$

$$\approx 2042970 \text{ LBS}$$

108 BOLTS

$$\therefore F_{BOLT} = 18920 \text{ LBS} \left\{ \begin{array}{l} \text{DUE TO PRESSURE} \\ \text{PLUS AXIAL LOAD} \end{array} \right.$$

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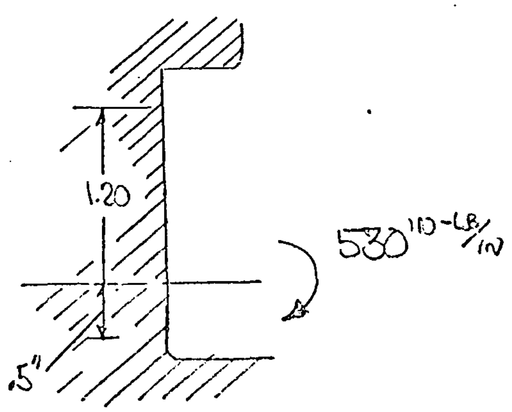
BOLT LOAD (CONT.)

MOMENT @ INTERFACE

MECH. ONLY



$M = Fd$

$F = \frac{530}{.5} = 1060\ ^{LBS}/_{IN}$

$F_{TOTAL} = 2\pi\,(23.133)\,1060$

$= 154000$ LBS

$F_{TOTAL}/_{BOLT} = 1426$ LBS/BOLT

MECH. + THERMAL (STEADY STATE)

$F = \frac{2947}{1.207} = 2442\ ^{LB}/_{IN}$

$F_{TOTAL} = 2\pi\,(23.133)\,2442$

$= 354762.$

$F_{TOTAL}/_{BOLT} = 3285\ ^{LBS}/_{BOLT}$

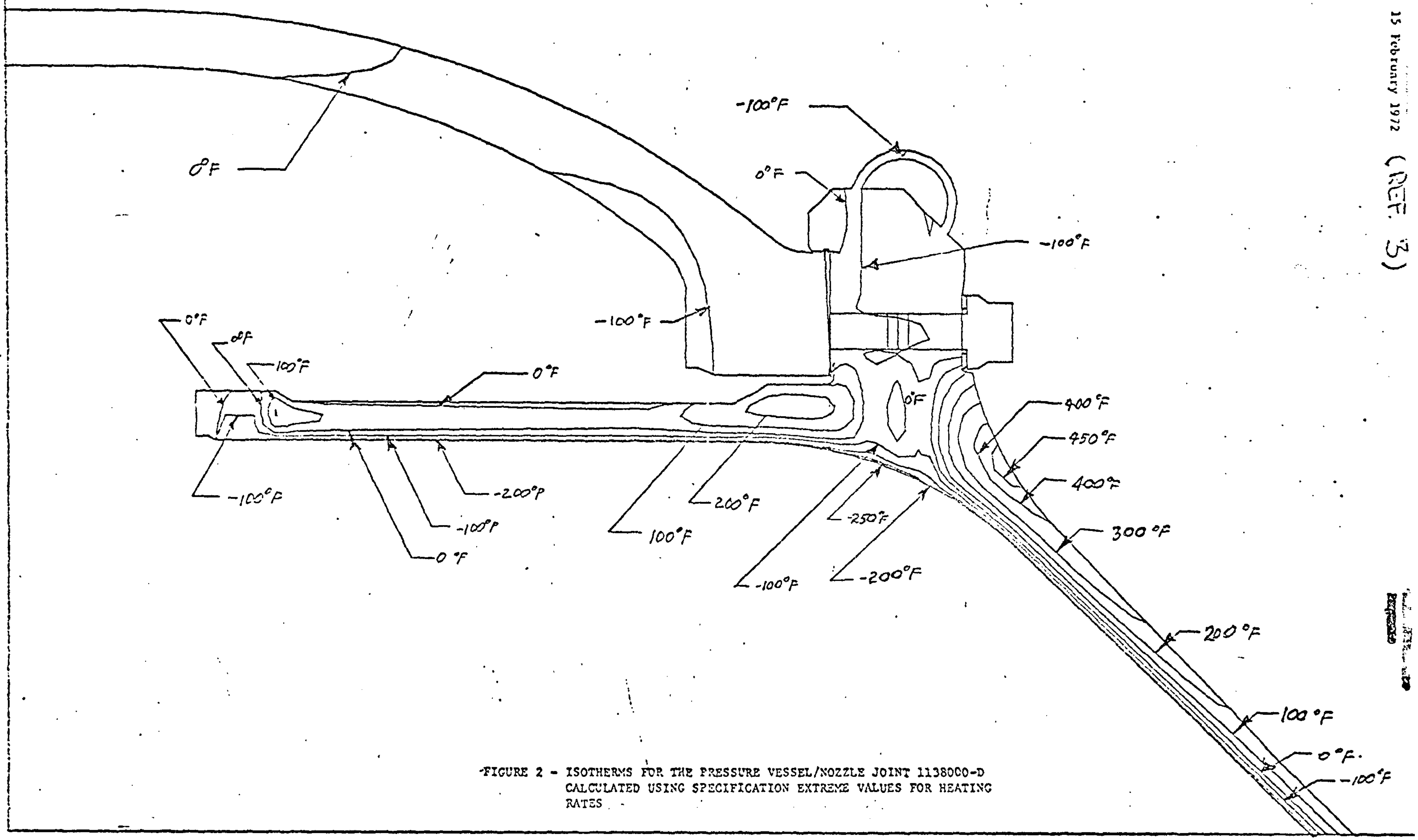


FIGURE 2 - ISOTHERMS FOR THE PRESSURE VESSEL/NOZZLE JOINT 1138000-D CALCULATED USING SPECIFICATION EXTREME VALUES FOR HEATING RATES

BOLT LOAD (CONT.)

MECHANICAL LOAD DUE TO THERMAL ENVIRONMENT

THE DIFFERENCE BETWEEN THE RELATIVE TEMPS. OF THE NOZZLE FLANGE AND BOLT WILL ALSO PRODUCE A LOAD IN THE BOLT. THIS LOAD IS DIFFICULT TO DETERMINE BECAUSE OF THE ASSUMPTIONS THAT HAVE TO BE MADE.

FLANGE DEFORMATION @ BOLT CIRCLE FROM F.E.M. MODEL

$$\delta_{FLANGE} = \delta_{z_{728}} - \delta_{z_{480}} \quad \text{BELOW BOLT } \odot$$
$$= .0434 - .0454$$
$$= 0.002$$

$$\delta_{FLANGE} = \delta_{z_{730}} - \delta_{z_{482}} \quad \text{ABOVE BOLT } \odot$$
$$= .0408 - .0432$$
$$= 0.0024$$

$$\text{AVERAGE } \delta_{FLANGE} \approx 0.0022$$

BOLT LOAD (CONT.)

USING THE BOLT TEMPS. FROM REF. 2

$$\delta_{BOLT} = \ell \alpha \Delta T$$

WHERE $T_{AU} = -235°F$

$$\therefore \delta_{BOLT} = (2.0)(7.6\times10^{-6})(-235-70)$$
$$= -.00464 \text{ IN}$$

THIS IS A RESULT OF STEADY STATE OPERATION. THERE IS A POSSIBILITY THAT UNDER A START-UP (ETC.) CONDITION THAT THE BOLT WOULD RUN COLDER (FOR A SMALL INCREMENT OF TIME).

~ ASSUME $T_{AU} = -350°F$

$$\delta_{BOLT} = (2.0)(7.0\times10^{-6})[-350-70]$$
$$= .00588$$

LOAD IN BOLT

$$\delta_{BOLT} - \delta_{FLANGE} = .00464 - .0022$$
$$= .00244$$

$$F_{BOLT_{-235°F}} = \frac{\Delta\delta\, AE}{\ell}$$
$$= \frac{(.00244)(.227)(29.7\times10^{6})}{2.0}$$
$$= 8225^{\#}$$

BOLT LOAD (CONT.)

LOAD IN BOLTS

	MECH. ONLY	MECH. + THERM.
$F_{AXIAL\ LOAD}$	18916	18916
$F_{AXIAL(MOMENT)}$	1426 *	3284 **
$F_{AXIAL}(\Delta T)$	—	8225
F_{TOTAL}	20342	30425
F_{ALL}	30600 ①	35600 ②
MS	+.5	+.17

* NEGATIVE MOMENT

ASSUME REACTION IS BETWEEN HEAL OF PV FLANGE AND BOLT

$$\therefore F = \frac{M}{d} = \frac{(-530)(2\pi)(23.133)}{.5} = 153992 \text{ lb}$$

** POSSITIVE MOMENT

$$F = \frac{M}{d} = \frac{(2947)(2\pi)(23.133)}{1.207} = 354703^{\#}$$

① $\sigma_{y_{RT}} = 159000$, $\sigma_{all} = .85\,\sigma_{y_{RT}} = 135000$

$F_{ALL} = (.227)(135000) = 306$

② $\sigma_{235} = 185000$, $\sigma_{all} = .85\,\sigma_{235} = 157000$

$F_{ALL} = (.227)(157000) = 35600$

MATERIAL PROPERTIES

MAT'L 1 ARMCO 22-13-5 ---- NOZZLE

MAT'L 2 7075-T73 -------- PRESSURE VESSEL

MAT'L 3 ARMCO 22-13-5 --- BOLT COOLANT MANIFOLD

MAT'L 4 A286 --------- BOLT

$E_r - E_z$ (REGULAR)

$E_\theta = 1\times10^3$, $\nu_\theta = 0.0$

MAT'L 5 ARMCO 22-13-5 ------ NOZZLE BOLT AREA

BOLT RADIUS = 23.133

BORE = 0.68" DIA.

103 BOLTS AT AN ANGLE OF 3.33° APPART ($\measuredangle$ =.058166 rad)

ARC LENGTH BETWEEN BOLT CENTER LINES:

ARC LENGTH $= r\theta$

$= (23.133)(.058166)$

$= 1.346$

LAND BETWEEN BOLTS $= 1.346 - .68$

$= 0.666$

C2

MATERIAL PROPERTIES (CONT.)

MAT'L 5 (CONT.)

AREA OF SECTION WITHOUT BOLT HOLES

$$A_{SECTOR} = \pi (R_o^2 - R_i^2)/2\pi \, [.058166]$$

$$= \frac{\cancel{\pi}(25.473^2 - 22.793^2)}{2\cancel{\pi}} [.058166]$$

$$= (15.73)(.05817)$$

$$= 0.915 \text{ IN}^2$$

$$A_{BORE} = \pi r^2$$

$$= \pi (.34)^2$$

$$= 0.363 \text{ IN}^2$$

$$A_{NET} = A_{SECTOR} - A_{BORE}$$

$$= 0.915 - .363$$

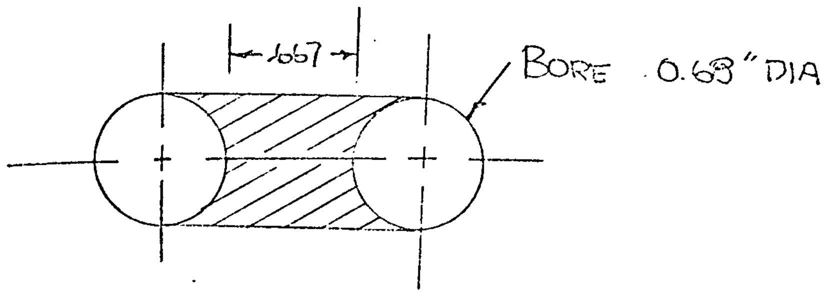
$$= 0.552 \text{ IN}^2$$

RATIO OF $\frac{A_{NET}}{A_{SECTOR}} = 0.603$

OR A 40% REMOVAL OF MATERIAL WHICH WILL BE TRANSLATED INTO A 40% REDUCTION IN THE MODULUS TO COMPENSATE FOR THAT MATERIAL REMOVED $(E_z - E_r)$.

MATERIAL PROPERTIES (CONT.)

MAT'L 5 (CONT.)



THE BOLT HOLES ARE LESS THAN A DIAMETER APPART THUS MAKING THE MATERIAL BETWEEN THE HOLES A LOW STRESS AREA (NO LOAD). TO SIMULATE THIS CONDITION THE MODULUS IN THE HOOP DIRECTION WILL BE MADE SMALL

$$\therefore E_\theta \equiv 1\times10^3$$

$$\nu_\theta \equiv 0.0$$

MAT'L 6 7075-T73 - PRESS. VESSEL BOLT HOLE

USE THE SAME FACTOR THATS APPLIED TO THE MATERIAL IN THE AREA OF THE NOZZLE BOLT HOLES.

$\therefore E_r - E_z \sim 40\%$ REDUCTION

$$E_\theta \equiv 1\times10^3$$

$$\nu_\theta \equiv 0.0$$

MATERIAL PROPERTIES (CONT.)

MAT'L 7 K-SEAL

ASSUME SAME PROPERTIES AS THE BOLT (A286) [MAT'L 4]

MAT'L 8 TRIANGLES (INTERFACE)

$$E_r - E_z = 50.0 \times 10^6$$

$$E_\theta = 1 \times 10^3$$

$$\nu_\theta = 0.0$$

MAT'L 9 ARMCO 22-13-5 - FUEL INLET HOLES

NOZZLE CORE SUPPORT FUEL INLET HOLES
216 HOLES AT AN ANGLE OF 1.667 ° APPART ($\measuredangle$ = .029 r

HOLE DIAM. = 0.437 IN

ARC LENGTH BETWEEN HOLE CENTERS = $r_{mean}\,\theta$

$$= \left(\frac{21.420 + 22.175}{2}\right)(.029)$$

$$= 0.632 \text{ IN}$$

MATERIAL PROPERTIES (CONT.)

MAT'L 9 (CONT.)

$$A_{SECTOR} = \frac{\cancel{\pi}(22.175^2 - 21.422^2)}{2\cancel{\pi}}(.029)$$

$$= 0.477 \text{ IN}^2$$

$$A_{HOLE} = 0.755(.437) = 0.33 \text{ IN}^2$$

$$A_{NET} = A_{SECTOR} - A_{HOLE}$$

$$= 0.477 - 0.33$$

$$= 0.147 \text{ IN}^2$$

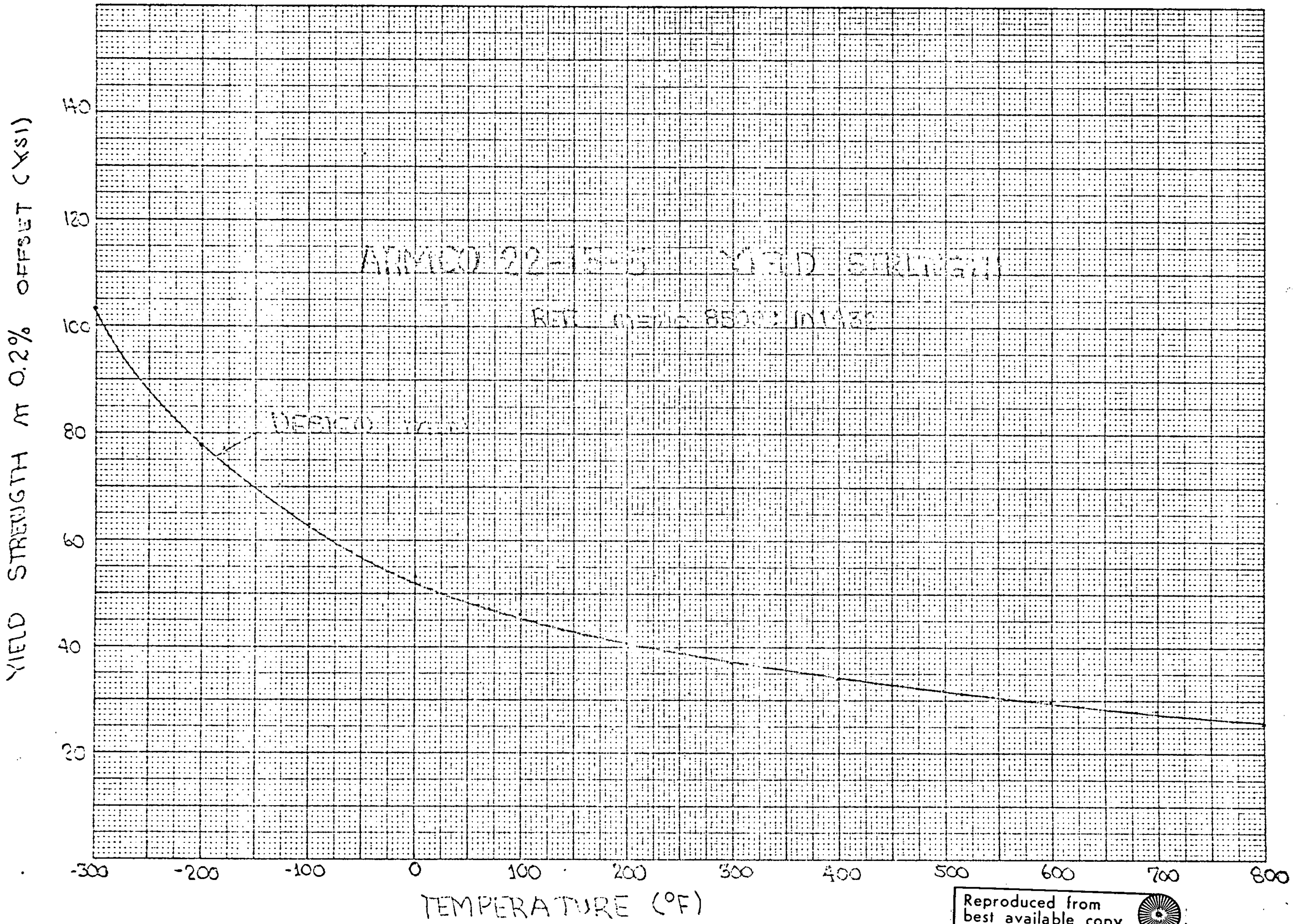
$$\text{RATIO OF } \frac{A_{NET}}{A_{SECTOR}} = \frac{.147}{.477} = 0.308$$

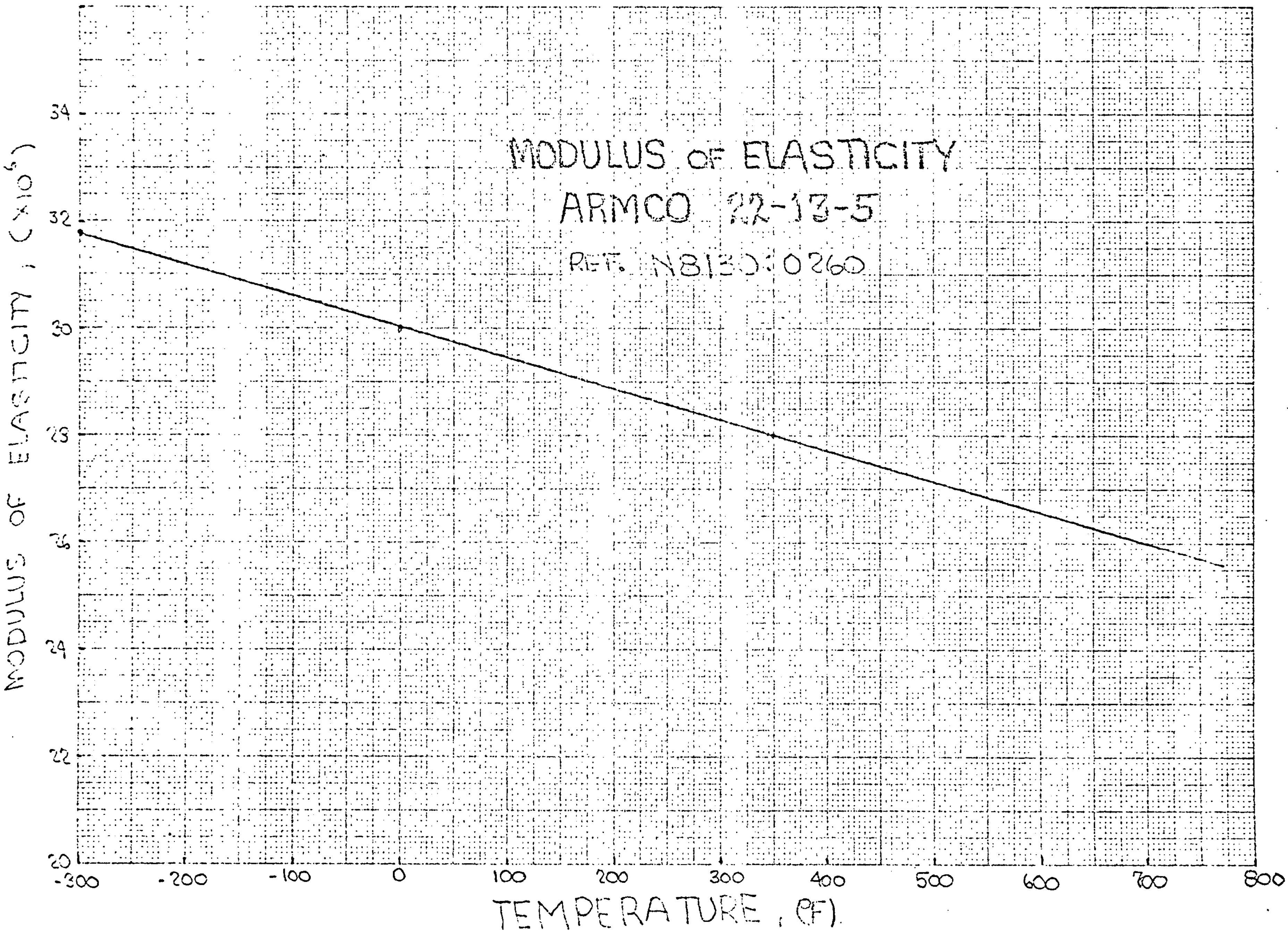
OR A ~70% REMOVAL OF MATERIAL WHICH WILL BE TRANSLATED INTO A 70% REDUCTION IN THE MODULUS TO COMPENSATE FOR THAT MATERIAL REMOVED.

THE COOLANT HOLES ARE LESS THAN A DIAMETER APPART THUS MAKING THE MATERIAL BETWEEN THE HOLES A LOW STRESS AREA (NO LOAD). TO SIMULATE THIS CONDITION THE MODULUS IN THE HOOP DIRECTION WILL BE MADE SMALL.

$$\therefore E_\Theta \cong 1 \times 10^3$$

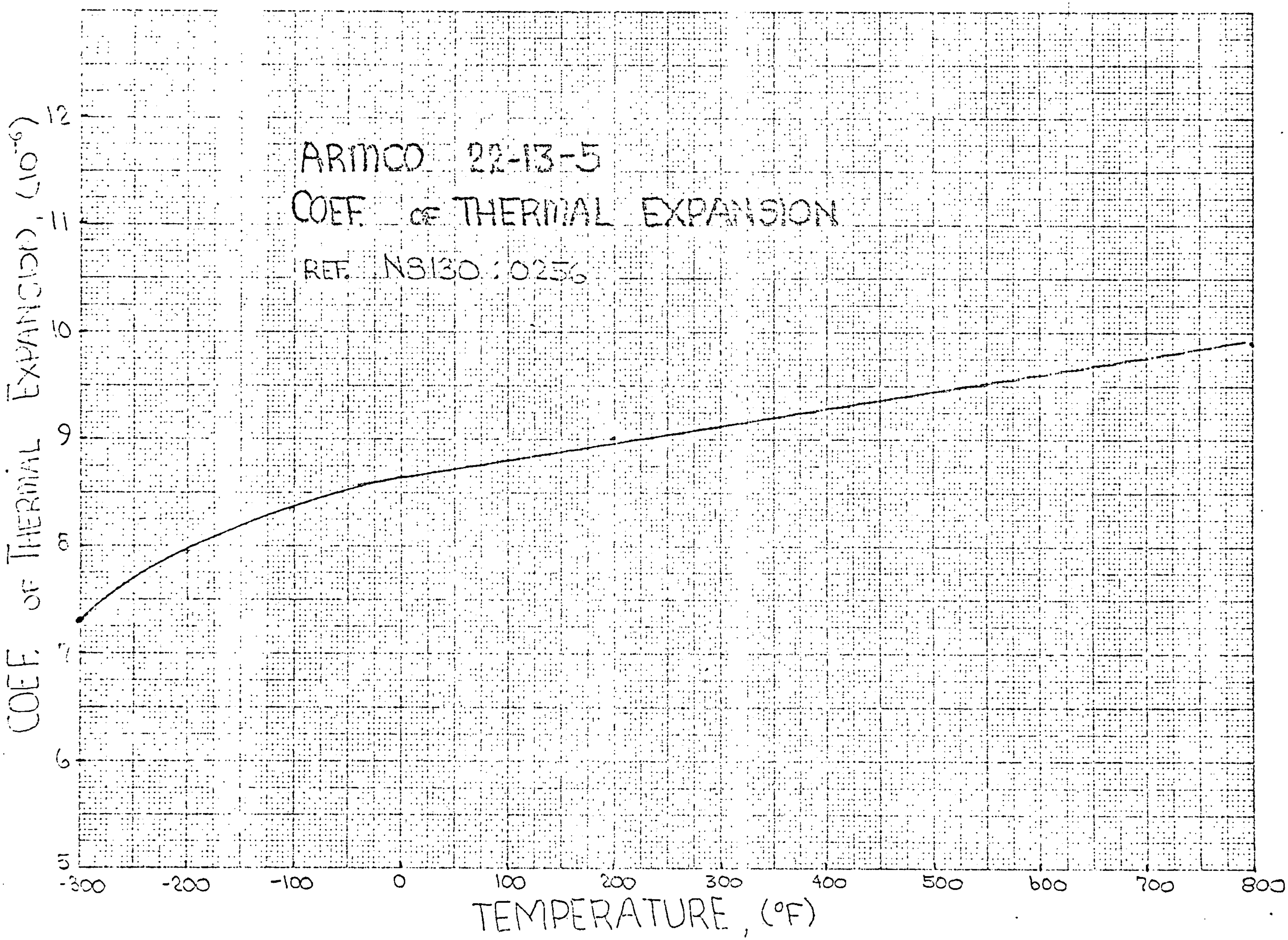
$$\& \ \nu_\Theta \cong 0.0$$


YIELD STRENGTH AT 0.2% OFFSET (KSI)
140
120
100
80
60
40
20
-300
-200
-100
0
100
200
300
400
500
600
700
800
TEMPERATURE (°F)



MODULUS OF ELASTICITY
ARMCO 22-13-5
REF. N8130:0260
MODULUS OF ELASTICITY, (x10⁶)
34
32
30
28
26
24
22
20
-300
-200
-100
0
100
200
300
400
500
600
700
800
TEMPERATURE, (°F)

31


ARMCO 22-13-5
COEF. OF THERMAL EXPANSION
REF. NS130:0256
COEF. OF THERMAL EXPANSION, (10⁻⁶)
12
11
10
9
8
7
6
5
-300
-200
-100
0
100
200
300
400
500
600
700
800
TEMPERATURE, (°F)
26

APPENDIX C

NOZZLE TUBE THERMAL ANALYSIS

AT MAXIMUM FLUX POINT AND BARREL SECTION

AEROJET NUCLEAR SYSTEMS COMPANY

SACRAMENTO, CALIFORNIA

CLASSIFICATION CATEGORY
Unclassified
O J Demuth 4-8-71
CLASSIFYING OFFICER DATE

8 April 1971
JJW:jm:N4320:M1672
Project 141
Work Statement 9

TO: J. L. Watkins

FROM: J. J. Williams

SUBJECT: Steady State Temperature Distributions in the NERVA Nozzle Coolant Channels

DISTRIBUTION: R. H. Coppo, O. J. Demuth, K. Sato, L. A. Shurley, E. A. Thomas, W. R. Thompson, P. P. Ventura (W/O Encl.), File

REFERENCES:

(a) Request from R. H. Coppo dated 3-31-71, "Heat Transfer Analysis for Tube Buckling Investigation - Coolant Channel Runs with Subsequent 2-D Thermal Runs"

(b) Memorandum N4320:M1671, E. A. Thomas to J. L. Watkins, Subject: "NERVA 75K Coolant Channel Steady State Temperature Distributions for $T_c = 4568^oR$ and 4318^oR With Minimum Nuclear Heating Rates"

(c) Memorandum N4340:6392M, J. C. Courtney to J. L. Watkins, dtd. 18 January 1971, Subject: "Estimated Minimum Nozzle Heating Rates"

ENCLOSURE:

(1) Tabulated Computer Output from Two-Dimensional Heat Transfer Analyses 2KFE008 Through 2KFE013

INTRODUCTION AND SUMMARY

This memorandum transmits results of the six nozzle coolant channel heat transfer analyses requested in Reference (a). Chamber temperature was 4318^oR for three of the analyses and 4568^oR for the other three. In all cases coolant flow was reduced from previously used values (Reference (b)) by 5 percent and minimum nuclear heating rates were used. For two of the analyses the gas-side heat transfer coefficient was increased to cause a 300 degree increase in previously calculated values (on a one-dimensional basis) of coolant channel wall temperature in the barrel zone. Complete tabulations of steady state

temperature distributions are presented along with summary tables of computed heat transfer coefficients and coolant tube crown temperature.

DISCUSSION

Steady state thermal analyses had previously been made of the coolant channels in the barrel and maximum flux zones of the nozzle to determine two-dimensional temperature distributions for throttling and full power conditions (Reference (b)). The purpose of the present analyses was to determine the effect of a 5 percent reduction in coolant flow on the computed temperatures. In addition, two of the runs were made with the gas-side heat transfer coefficient in the barrel zone increased to cause a 300 degree rise in tube crown temperature. These runs were also made with the 5 percent reduction in coolant flow. In all cases the nuclear heating rates utilized were the values obtained by considering both prompt and delayed gamma radiation from a composite core. These rates are 0.249 Btu/sec/cu-in. in the barrel and 0.104 Btu/sec/cu-in. in the maximum flux zone, and are somewhat higher than those shown in Reference (c). The specific engine operating conditions for each analysis are shown in Table 1.

Convective film coefficients and coolant bulk temperatures were obtained from computer code E25104 using the land and groove configuration option along with the other options previously utilized in Reference (b). The specific run numbers are also shown in Table 1.

The steady state temperature distributions were computed using code E12401, a computer code for calculating two-dimensional, steady state temperature distributions by the finite element method. The gas-side heat transfer coefficients were assumed to vary from the maximum value at the crown of the tube in a cosine distribution to the vicinity of the brazing shim and then were retained at a constant value over the surface of the braze and shim. The angle defining the distribution was that between the vertical, the center of the tube and the selected surface element. The maximum value of heat transfer coefficient was that obtained from computer code E25105, and included both convective and thermal radiation effects.

The liquid-side heat transfer coefficient was assumed constant over the inside periphery of the flow channel at each station analyzed. Values for gas and liquid-side heat transfer coefficients, gas recovery temperature and

liquid bulk temperature are shown in Table 2. In addition, the calculated tube crown temperature is also shown for each case.

The detailed temperature distributions calculated for each case are shown in the computer output listings of Enclosure (1). Case identification is shown as part of the printed output on each page and the indicated run numbers correspond to those in Table 2.

The node numbering systems used for barrel and maximum flux station analyses are depicted on Figure 1. In addition to the node points and temperatures, the printed outputs also contain a tabular listing of the coordinates of each node.

In this type of conduction analysis small irregularities in computed temperatures can arise from the use of straight line segments to represent circular arcs and from rounding off values of convective heat transfer specified along the boundaries. Based on a review of the tabulated results, it is estimated that irregularities from these sources are on the order of 5 degrees F or less which is considered acceptable. No indication of abnormal temperature distributions could be detected on isotherm plots that were generated as part of this study.

In addition to the enclosed tabulated temperatures, punch cards containing coordinate location, node number and computed temperature information are available for each run. These will be retained so they will be available for possible use in subsequent stress analyses.

J J Williams
J. J. Williams, Sr. Engr. Spec.
Thermophysics
Engineering Staff Department

TABLE 1 - ENGINE OPERATING CONDITIONS ASSUMED FOR ANALYSES

RUN	STAGNATION CONDITIONS TEMPERATURE (DEG R)	STAGNATION CONDITIONS PRESSURE (PSIA)	NOZZLE FLOW (LB/SEC)	COOLANT FLOW (LB/SEC)	COOLANT INLET CONDITIONS TEMPERATURE (DEG R)	COOLANT INLET CONDITIONS PRESSURE (PSIA)	COMMENTS
2KSP008	4318.	442.	89.1	69.5	56.6	1287.	Maximum Flux Station (22)
2KSP009	4318.	285.	57.2	36.8	49.9	747.	Barrel Station (35)
2KSP010	4318.	285.	57.2	36.8	49.9	747.	Barrel Modified Cg's
2KSP011	4568.	442.	86.4	65.3	57.9	1279.	Max Flux
2KSP012	4568.	292.	56.6	37.4	52.7	780.	Barrel
2KSP013	4568.	292.	56.6	37.4	52.7	780.	Barrel Modified Cg's

TABLE 2 - TWO DIMENSIONAL CONDUCTION BOUNDARY CONDITIONS AND COMPUTED MAXIMUM CROWN TEMPERATURES

RUN (1)	REFERENCE RUN	GAS RECOVERY TEMPERATURE (DEG R)	LIQUID BULK TEMPERATURE (DEG R)	GAS SIDE HEAT TRANSFER COEFFICIENT (BTU/SEC/SQ-IN/DEG R)	LIQUID SIDE HEAT TRANSFER COEFFICIENT (BTU/SEC/SQ-IN/DEG R)	MAX TUBE CROWN TEMPERATURE (DEG R)
2KFE008	2KSP008	4274.	108.7	0.00752	0.01981	1959.
2KFE009	2KSP009	4274.	200.0	0.00159	0.00452	1571.
2KFE010	2KSP010	4274.	206.4	0.00211	0.00448	1832.
2KFE011	2KSP011	4522.	116.0	0.00757	0.01960	2072.
2KFE012	2KSP012	4522.	215.0	0.00163	0.00467	1658.
2KFE013	2KSP013	4522.	219.7	0.00217	0.00461	1940.

(1) All analyses run with minumun nuclear heating rate (0.104 Btu/cu-in/sec at max flux station and 0.249 in barrel)

Enclosure (1)
N4320:M1672

TABULATED COMPUTER OUTPUT FROM TWO-
DIMENSIONAL HEAT TRANSFER ANALYSES
2KFE008 THROUGH 2KFE013

5

B

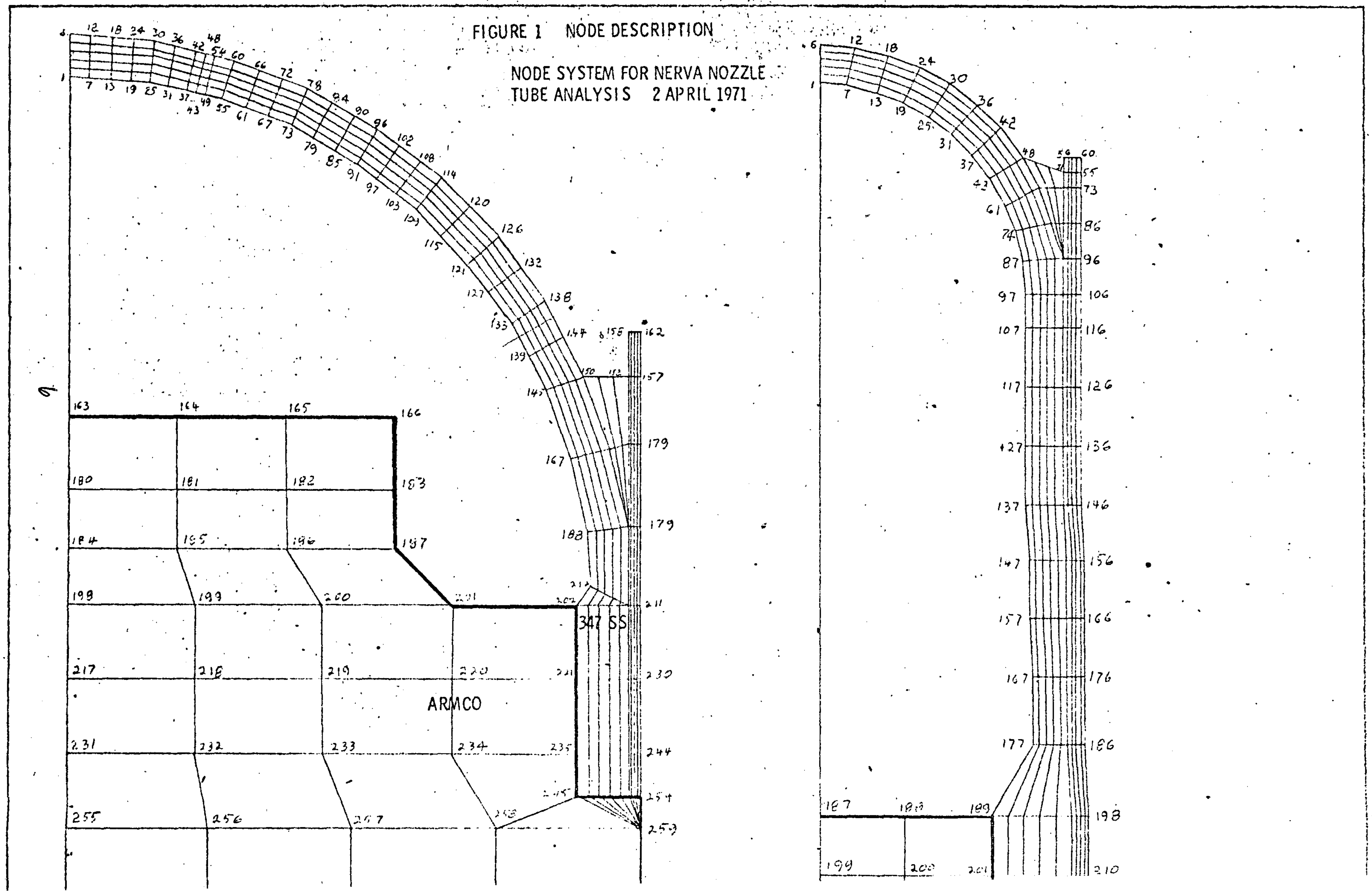
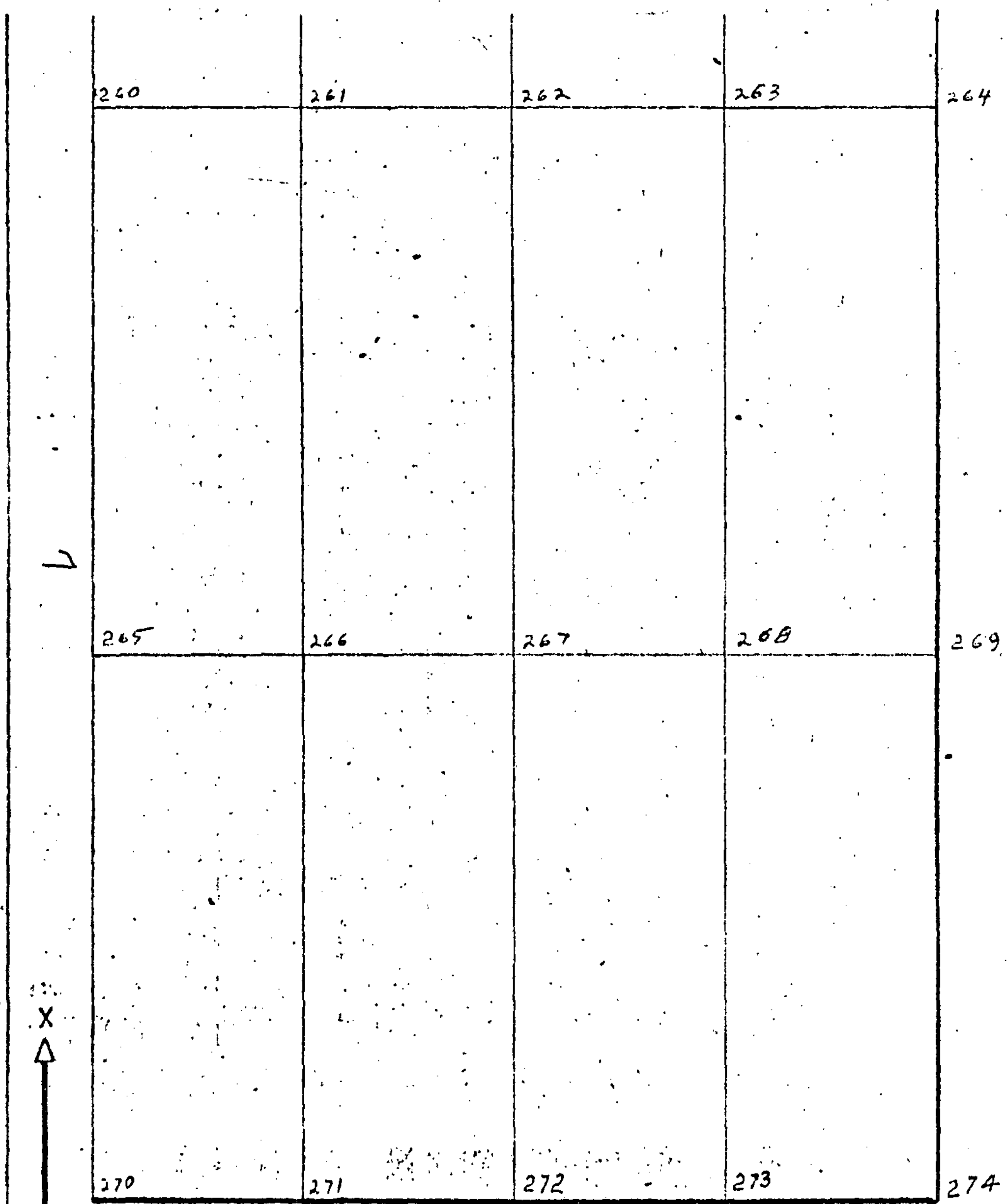
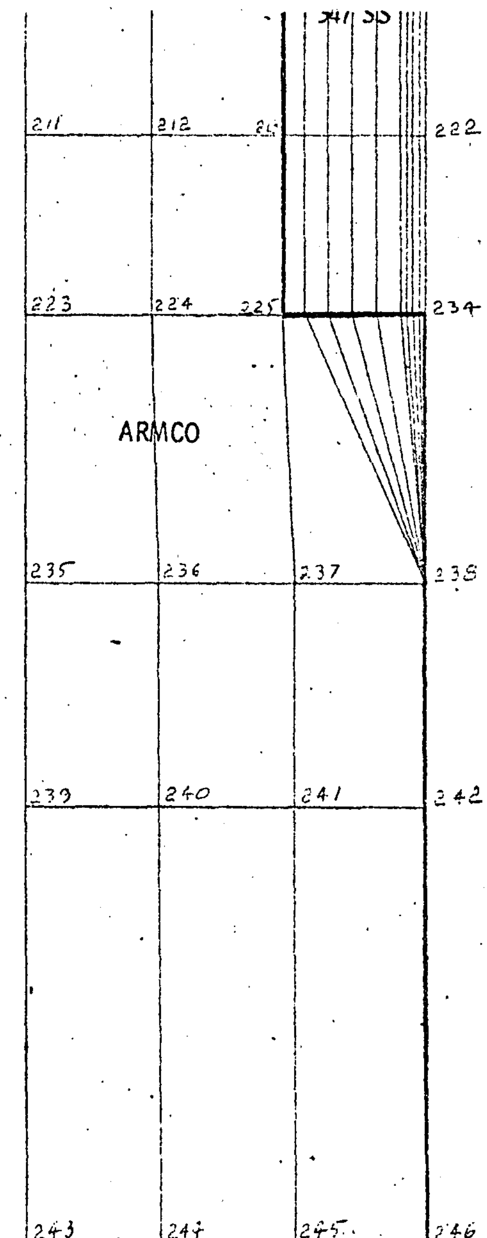


FIGURE 1 NODE DESCRIPTION

NODE SYSTEM FOR NERVA NOZZLE TUBE ANALYSIS 2 APRIL 1971



BARREL SECTION - STATION 35
FROM ANSC SKETCH 4261-09-033
SCALE 22:1



MAXIMUM FLUX SECTION - STATION 22
FROM ANSC SKETCH 4261-09-033
SCALE 35:1

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM F124C1   STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

. MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE008   5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
1	0	1.563	1.000	1151.23
2	0	1.566	1.000	1342.67
3	0	1.565	1.000	1514.17
4	0	1.571	1.000	1672.43
5	0	1.573	1.000	1820.18
6	0	1.576	1.000	1958.89
7	0	1.562	1.010	1134.04
8	0	1.565	1.010	1325.95
9	0	1.567	1.011	1478.39
10	0	1.570	1.011	1657.48
11	0	1.572	1.012	1806.29
12	0	1.575	1.012	1946.25
13	0	1.559	1.020	1076.44
14	0	1.562	1.021	1271.45
15	0	1.564	1.022	1447.88
16	0	1.567	1.022	1610.34
17	0	1.569	1.023	1762.53
18	0	1.572	1.024	1905.80
19	0	1.556	1.029	1074.11
20	0	1.558	1.030	1262.14
21	0	1.561	1.031	1431.69
22	0	1.563	1.033	1537.02
23	0	1.566	1.034	1732.64
24	0	1.563	1.035	1869.82
25	0	1.551	1.038	1022.82
26	0	1.553	1.039	1213.40
27	0	1.556	1.041	1385.41
28	0	1.558	1.042	1542.15
29	0	1.561	1.044	1688.69
30	0	1.563	1.045	1826.64
31	0	1.545	1.046	965.69
32	0	1.547	1.048	1142.09
33	0	1.549	1.050	1301.95
34	0	1.551	1.051	1447.95
35	0	1.553	1.053	1593.50
36	0	1.555	1.055	1711.69
37	0	1.538	1.053	891.07
38	0	1.540	1.055	1059.13
39	0	1.542	1.057	1211.53
40	0	1.543	1.059	1351.78
41	0	1.545	1.061	1481.32
42	0	1.547	1.063	1602.61
43	0	1.530	1.059	793.50
44	0	1.531	1.061	943.13
45	0	1.533	1.063	1090.44
46	0	1.534	1.066	1203.37
47	0	1.536	1.068	1329.02
48	0	1.537	1.070	1443.55
49	0	1.535	1.075	1514.57
50	0	1.534	1.079	1577.14
51	0	1.532	1.084	1674.65
52	0	1.532	1.086	1683.68
53	0	1.532	1.087	1695.32
54	0	1.532	1.088	1695.73
55	0	1.532	1.090	1686.70
56	0	1.538	1.084	2058.15
57	0	1.539	1.086	2001.99
58	0	1.538	1.087	1969.42
59	0	1.538	1.088	1952.44
60	0	1.538	1.090	1947.17

PROGRAM E[illegible]01 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE008 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
61	0	1.521	1.064	657.57
62	0	1.522	1.066	791.07
63	0	1.523	1.069	914.79
64	0	1.525	1.071	1030.76
65	0	1.526	1.074	1141.10
66	0	1.527	1.076	1247.63
67	0	1.527	1.079	1310.30
68	0	1.527	1.081	1366.18
69	0	1.527	1.084	1403.91
70	0	1.527	1.086	1421.21
71	0	1.527	1.087	1433.06
72	0	1.527	1.088	1439.90
73	0	1.527	1.090	1442.12
74	0	1.512	1.068	514.63
75	0	1.513	1.070	607.76
76	0	1.513	1.073	690.46
77	0	1.514	1.075	764.41
78	0	1.514	1.078	830.33
79	0	1.515	1.080	888.75
80	0	1.515	1.081	904.32
81	0	1.515	1.083	917.46
82	0	1.515	1.084	929.44
83	0	1.515	1.086	940.92
84	0	1.515	1.087	949.24
85	0	1.515	1.088	954.28
86	0	1.515	1.090	955.97
87	0	1.502	1.070	349.10
88	0	1.502	1.073	420.97
89	0	1.502	1.076	480.05
90	0	1.503	1.078	527.69
91	0	1.503	1.081	564.81
92	0	1.503	1.084	592.06
93	0	1.503	1.086	601.12
94	0	1.503	1.087	607.55
95	0	1.503	1.088	611.40
96	0	1.503	1.090	612.68
97	0	1.491	1.071	232.47
98	0	1.491	1.074	275.44
99	0	1.491	1.076	309.91
100	0	1.491	1.079	337.59
101	0	1.491	1.081	359.25
102	0	1.491	1.084	375.15
103	0	1.491	1.086	381.74
104	0	1.491	1.087	386.44
105	0	1.491	1.088	389.25
106	0	1.491	1.090	390.19
107	0	1.479	1.071	166.05
108	0	1.479	1.074	190.54
109	0	1.479	1.076	210.76
110	0	1.479	1.079	227.25
111	0	1.479	1.081	240.31
112	0	1.479	1.084	249.90
113	0	1.479	1.086	253.88
114	0	1.479	1.087	256.71
115	0	1.479	1.088	258.41
116	0	1.479	1.090	258.98
117	0	1.459	1.071	116.82
118	0	1.459	1.074	126.24
119	0	1.459	1.076	134.27
120	0	1.459	1.079	140.93

PROGRAM E12401   STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE008   5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
121	0	1.459	1.081	146.21
122	0	1.459	1.084	150.12
123	0	1.459	1.086	151.74
124	0	1.459	1.087	152.90
125	0	1.459	1.088	153.60
126	0	1.459	1.090	153.83
127	0	1.439	1.071	112.40
128	0	1.439	1.074	114.03
129	0	1.439	1.076	115.64
130	0	1.439	1.079	117.12
131	0	1.439	1.081	118.38
132	0	1.439	1.084	119.35
133	0	1.439	1.086	119.77
134	0	1.439	1.087	120.07
135	0	1.439	1.088	120.25
136	0	1.439	1.090	120.31
137	0	1.419	1.071	108.92
138	0	1.419	1.074	109.60
139	0	1.419	1.076	110.17
140	0	1.419	1.079	110.64
141	0	1.419	1.081	111.02
142	0	1.419	1.084	111.30
143	0	1.419	1.086	111.42
144	0	1.419	1.087	111.50
145	0	1.419	1.088	111.54
146	0	1.419	1.090	111.56
147	0	1.400	1.072	109.13
148	0	1.400	1.075	109.24
149	0	1.400	1.077	109.36
150	0	1.400	1.080	109.46
151	0	1.400	1.082	109.55
152	0	1.400	1.085	109.62
153	0	1.400	1.087	109.65
154	0	1.400	1.088	109.67
155	0	1.400	1.090	109.68
156	0	1.400	1.091	109.68
157	0	1.380	1.072	108.73
158	0	1.380	1.075	108.86
159	0	1.380	1.077	108.97
160	0	1.380	1.080	109.06
161	0	1.380	1.082	109.13
162	0	1.380	1.085	109.18
163	0	1.380	1.087	109.20
164	0	1.380	1.088	109.22
165	0	1.380	1.090	109.23
166	0	1.380	1.091	109.23
167	0	1.360	1.073	109.01
168	0	1.360	1.075	109.07
169	0	1.360	1.078	109.13
170	0	1.360	1.080	109.19
171	0	1.360	1.083	109.25
172	0	1.360	1.085	109.29
173	0	1.360	1.087	109.31
174	0	1.360	1.088	109.32
175	0	1.360	1.090	109.33
176	0	1.360	1.091	109.33
177	0	1.337	1.073	108.82
178	0	1.337	1.075	109.29
179	0	1.337	1.078	109.69
180	0	1.337	1.080	110.02

PROGRAM EI2401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE008 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
181	0	1.337	1.083	110.29
182	0	1.337	1.085	110.50
183	0	1.337	1.087	110.60
184	0	1.337	1.088	110.67
185	0	1.337	1.090	110.72
186	0	1.337	1.091	110.74
187	0	1.313	1.000	110.93
188	0	1.313	1.030	109.40
189	0	1.313	1.059	112.06
190	0	1.313	1.064	113.60
191	0	1.313	1.070	114.79
192	0	1.313	1.075	115.65
193	0	1.313	1.081	116.26
194	0	1.313	1.086	116.62
195	0	1.313	1.088	116.68
196	0	1.313	1.089	116.73
197	0	1.313	1.090	116.76
198	0	1.313	1.092	116.77
199	0	1.293	1.000	121.85
200	0	1.293	1.030	121.90
201	0	1.293	1.059	123.02
202	0	1.293	1.064	123.14
203	0	1.293	1.070	123.33
204	0	1.293	1.075	123.53
205	0	1.293	1.081	123.69
206	0	1.293	1.086	123.80
207	0	1.293	1.088	123.82
208	0	1.293	1.089	123.83
209	0	1.293	1.090	123.84
210	0	1.293	1.092	123.84
211	0	1.253	1.000	138.97
212	0	1.253	1.030	138.93
213	0	1.253	1.059	138.66
214	0	1.253	1.064	138.62
215	0	1.253	1.070	138.58
216	0	1.253	1.075	138.54
217	0	1.253	1.081	138.51
218	0	1.253	1.086	138.49
219	0	1.253	1.088	138.49
220	0	1.253	1.089	138.49
221	0	1.253	1.090	138.48
222	0	1.253	1.092	138.48
223	0	1.212	1.000	151.76
224	0	1.212	1.030	151.59
225	0	1.212	1.059	150.96
226	0	1.212	1.064	150.77
227	0	1.212	1.070	150.65
228	0	1.212	1.075	150.55
229	0	1.212	1.081	150.49
230	0	1.212	1.086	150.45
231	0	1.212	1.088	150.45
232	0	1.212	1.089	150.44
233	0	1.212	1.090	150.44
234	0	1.212	1.092	150.45
235	0	1.151	1.000	165.45
236	0	1.151	1.031	165.43
237	0	1.151	1.062	165.43
238	0	1.151	1.093	165.61
239	0	1.100	1.000	173.12
240	0	1.100	1.031	173.12

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE008 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
241	0	1.100	1.062	173.13
242	0	1.100	1.093	173.13
243	0	1.000	1.000	178.92
244	0	1.000	1.031	178.92
245	0	1.000	1.062	178.92
246	0	1.000	1.093	178.92

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE009 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
1	0	1.885	1.000	1216.95
2	0	1.890	1.000	1293.52
3	0	1.894	1.000	1366.82
4	0	1.899	1.000	1437.13
5	0	1.903	1.000	1504.82
6	0	1.908	1.000	1570.64
7	0	1.885	1.010	1219.39
8	0	1.889	1.010	1292.70
9	0	1.894	1.010	1362.93
10	0	1.898	1.011	1430.38
11	0	1.903	1.011	1495.31
12	0	1.907	1.011	1558.40
13	0	1.884	1.023	1213.51
14	0	1.888	1.023	1296.96
15	0	1.893	1.024	1357.39
16	0	1.897	1.024	1425.05
17	0	1.902	1.025	1490.16
18	0	1.906	1.025	1553.44
19	0	1.883	1.034	1212.24
20	0	1.887	1.034	1285.61
21	0	1.892	1.035	1355.96
22	0	1.896	1.035	1423.51
23	0	1.901	1.036	1488.50
24	0	1.905	1.036	1551.61
25	0	1.882	1.044	1214.62
26	0	1.886	1.045	1288.70
27	0	1.891	1.046	1359.55
28	0	1.895	1.046	1427.50
29	0	1.900	1.047	1492.85
30	0	1.904	1.048	1556.30
31	0	1.880	1.054	1206.33
32	0	1.884	1.055	1280.34
33	0	1.889	1.056	1351.22
34	0	1.893	1.056	1419.24
35	0	1.898	1.057	1484.69
36	0	1.902	1.058	1548.25
37	0	1.877	1.065	1190.59
38	0	1.881	1.066	1264.31
39	0	1.886	1.067	1335.17
40	0	1.890	1.067	1403.30
41	0	1.895	1.068	1468.90
42	0	1.899	1.069	1532.49
43	0	1.876	1.070	1191.09
44	0	1.880	1.071	1264.49
45	0	1.885	1.072	1335.11
46	0	1.889	1.072	1403.03
47	0	1.894	1.073	1468.46
48	0	1.898	1.074	1531.94
49	0	1.875	1.075	1192.29
50	0	1.879	1.076	1263.17
51	0	1.883	1.077	1331.32
52	0	1.888	1.078	1396.88
53	0	1.892	1.079	1460.08
54	0	1.896	1.080	1521.34
55	0	1.873	1.084	1194.22
56	0	1.877	1.085	1262.70
57	0	1.881	1.086	1328.36
58	0	1.885	1.088	1391.49
59	0	1.889	1.089	1452.34
60	0	1.893	1.090	1511.26

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE009 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
61	0	1.868	1.096	1168.45
62	0	1.872	1.098	1238.31
63	0	1.876	1.099	1305.56
64	0	1.880	1.101	1370.27
65	0	1.884	1.102	1432.65
66	0	1.888	1.104	1492.95
67	0	1.863	1.109	1155.02
68	0	1.867	1.111	1224.32
69	0	1.871	1.112	1291.21
70	0	1.875	1.114	1355.63
71	0	1.879	1.115	1417.71
72	0	1.883	1.117	1477.59
73	0	1.859	1.122	1163.15
74	0	1.863	1.124	1229.47
75	0	1.867	1.125	1293.00
76	0	1.870	1.127	1354.01
77	0	1.874	1.128	1412.77
78	0	1.878	1.130	1469.53
79	0	1.852	1.133	1127.21
80	0	1.856	1.135	1195.47
81	0	1.860	1.137	1261.09
82	0	1.863	1.139	1324.19
83	0	1.867	1.141	1384.90
84	0	1.871	1.143	1443.40
85	0	1.845	1.145	1107.18
86	0	1.849	1.147	1175.52
87	0	1.853	1.149	1241.53
88	0	1.856	1.152	1305.23
89	0	1.860	1.154	1366.65
90	0	1.864	1.156	1425.95
91	0	1.839	1.157	1106.38
92	0	1.842	1.159	1169.00
93	0	1.846	1.161	1229.21
94	0	1.849	1.164	1287.30
95	0	1.853	1.166	1343.40
96	0	1.856	1.168	1397.71
97	0	1.831	1.167	1073.28
98	0	1.834	1.170	1135.84
99	0	1.837	1.172	1196.00
100	0	1.841	1.175	1253.98
101	0	1.844	1.177	1309.92
102	0	1.847	1.180	1363.94
103	0	1.822	1.178	1044.40
104	0	1.825	1.181	1108.22
105	0	1.829	1.183	1169.87
106	0	1.832	1.186	1229.40
107	0	1.836	1.188	1286.90
108	0	1.839	1.191	1342.35
109	0	1.814	1.189	1034.29
110	0	1.817	1.192	1096.52
111	0	1.820	1.195	1156.33
112	0	1.824	1.197	1214.00
113	0	1.827	1.200	1269.77
114	0	1.830	1.203	1323.77
115	0	1.799	1.203	978.58
116	0	1.802	1.206	1040.69
117	0	1.805	1.209	1100.37
118	0	1.808	1.213	1157.90
119	0	1.811	1.216	1213.43
120	0	1.814	1.219	1267.08

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE009 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
121	0	1.784	1.217	939.72
122	0	1.787	1.220	1001.66
123	0	1.790	1.224	1061.14
124	0	1.793	1.227	1118.50
125	0	1.796	1.231	1174.02
126	0	1.799	1.234	1227.90
127	0	1.767	1.229	877.68
128	0	1.770	1.233	935.22
129	0	1.772	1.236	990.67
130	0	1.775	1.240	1044.15
131	0	1.777	1.243	1095.81
132	0	1.780	1.247	1145.80
133	0	1.752	1.241	845.54
134	0	1.754	1.245	899.23
135	0	1.757	1.248	950.78
136	0	1.759	1.252	1000.38
137	0	1.762	1.255	1048.30
138	0	1.764	1.259	1094.76
139	0	1.733	1.250	767.96
140	0	1.735	1.254	819.67
141	0	1.737	1.258	869.24
142	0	1.739	1.262	916.99
143	0	1.741	1.266	962.50
144	0	1.743	1.270	1005.96
145	0	1.717	1.260	734.26
146	0	1.718	1.264	773.55
147	0	1.720	1.268	821.28
148	0	1.721	1.272	861.01
149	0	1.723	1.276	910.12
150	0	1.724	1.280	951.55
151	0	1.724	1.288	1020.77
152	0	1.724	1.297	1092.48
153	0	1.724	1.305	1175.19
154	0	1.724	1.307	1150.28
155	0	1.724	1.308	1183.82
156	0	1.724	1.309	1185.90
157	0	1.724	1.311	1186.59
158	0	1.748	1.305	1676.86
159	0	1.748	1.307	1663.47
160	0	1.748	1.308	1654.07
161	0	1.748	1.309	1648.49
162	0	1.748	1.311	1645.65
163	0	1.703	1.000	221.19
164	0	1.703	1.059	220.00
165	0	1.703	1.119	216.80
166	0	1.703	1.178	292.13
167	0	1.680	1.273	519.94
168	0	1.681	1.277	550.83
169	0	1.682	1.281	579.65
170	0	1.683	1.286	606.56
171	0	1.684	1.290	631.57
172	0	1.685	1.294	654.51
173	0	1.686	1.298	669.55
174	0	1.687	1.301	681.95
175	0	1.688	1.305	690.89
176	0	1.688	1.307	692.26
177	0	1.688	1.308	693.25
178	0	1.688	1.309	693.85
179	0	1.688	1.311	694.06
180	0	1.663	1.000	252.79

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM [illegible]2401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE009 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
181	0	1.663	1.059	250.50
182	0	1.663	1.119	241.14
183	0	1.663	1.178	215.21
184	0	1.631	1.000	274.92
185	0	1.631	1.059	272.14
186	0	1.631	1.119	261.77
187	0	1.631	1.178	229.85
188	0	1.640	1.282	329.42
189	0	1.641	1.287	346.65
190	0	1.641	1.291	360.85
191	0	1.642	1.296	372.16
192	0	1.642	1.300	380.58
193	0	1.643	1.305	386.16
194	0	1.643	1.307	387.10
195	0	1.643	1.308	387.76
196	0	1.643	1.309	388.16
197	0	1.643	1.311	388.29
198	0	1.600	1.000	295.02
199	0	1.600	1.069	291.27
200	0	1.600	1.139	276.67
201	0	1.600	1.208	241.56
202	0	1.600	1.277	259.43
203	0	1.600	1.283	268.73
204	0	1.600	1.288	276.22
205	0	1.600	1.294	281.80
206	0	1.600	1.299	285.25
207	0	1.600	1.305	286.40
208	0	1.600	1.307	286.94
209	0	1.600	1.308	287.32
210	0	1.600	1.309	287.55
211	0	1.600	1.311	287.62
212	0	1.610	1.284	273.53
213	0	1.608	1.288	279.75
214	0	1.607	1.292	284.12
215	0	1.605	1.296	286.88
216	0	1.603	1.300	288.29
217	0	1.560	1.000	319.06
218	0	1.560	1.069	315.88
219	0	1.560	1.139	305.35
220	0	1.560	1.208	291.76
221	0	1.560	1.277	298.25
222	0	1.560	1.283	298.32
223	0	1.560	1.288	298.66
224	0	1.560	1.294	299.11
225	0	1.560	1.299	299.58
226	0	1.560	1.305	300.04
227	0	1.560	1.307	300.06
228	0	1.560	1.308	300.07
229	0	1.560	1.309	300.08
230	0	1.560	1.311	300.08
231	0	1.520	1.000	341.20
232	0	1.520	1.069	338.91
233	0	1.520	1.139	332.54
234	0	1.520	1.208	326.21
235	0	1.520	1.277	325.94
236	0	1.520	1.283	326.02
237	0	1.520	1.288	326.05
238	0	1.520	1.294	326.05
239	0	1.520	1.299	326.03
240	0	1.520	1.305	325.99

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE009 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
241	0	1.520	1.307	326.00
242	0	1.520	1.308	326.00
243	0	1.520	1.309	326.00
244	0	1.520	1.311	326.00
245	0	1.498	1.277	340.02
246	0	1.498	1.283	339.86
247	0	1.498	1.288	339.73
248	0	1.498	1.294	339.62
249	0	1.498	1.299	339.54
250	0	1.498	1.305	339.49
251	0	1.498	1.307	339.49
252	0	1.498	1.308	339.47
253	0	1.498	1.309	339.47
254	0	1.498	1.311	339.46
255	0	1.480	1.000	361.34
256	0	1.480	1.078	359.47
257	0	1.480	1.156	355.07
258	0	1.480	1.233	351.88
259	0	1.480	1.311	350.69
260	0	1.400	1.000	395.33
261	0	1.400	1.078	394.67
262	0	1.400	1.156	393.14
263	0	1.400	1.233	391.73
264	0	1.400	1.311	391.18
265	0	1.200	1.000	440.40
266	0	1.200	1.078	440.35
267	0	1.200	1.156	440.22
268	0	1.200	1.233	440.08
269	0	1.200	1.311	440.03
270	0	1.000	1.000	426.04
271	0	1.000	1.078	426.03
272	0	1.000	1.156	426.01
273	0	1.000	1.233	425.98
274	0	1.000	1.311	425.97

PROGRAM S[illegible]2401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE010 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
1	0	1.885	1.000	1437.43
2	0	1.890	1.000	1521.63
3	0	1.894	1.000	1603.01
4	0	1.899	1.000	1681.77
5	0	1.903	1.000	1758.10
6	0	1.908	1.000	1832.23
7	0	1.885	1.010	1440.11
8	0	1.889	1.010	1520.72
9	0	1.894	1.010	1598.68
10	0	1.898	1.011	1674.19
11	0	1.903	1.011	1747.43
12	0	1.907	1.011	1818.52
13	0	1.884	1.023	1433.65
14	0	1.888	1.023	1514.40
15	0	1.893	1.024	1592.55
16	0	1.897	1.024	1668.28
17	0	1.902	1.025	1741.72
18	0	1.906	1.025	1813.04
19	0	1.883	1.034	1432.30
20	0	1.887	1.034	1512.97
21	0	1.892	1.035	1591.02
22	0	1.896	1.035	1666.61
23	0	1.901	1.036	1739.90
24	0	1.905	1.036	1811.02
25	0	1.882	1.044	1435.0[illegible]
26	0	1.886	1.045	1516.48
27	0	1.891	1.046	1595.13
28	0	1.895	1.046	1671.21
29	0	1.900	1.047	1744.93
30	0	1.904	1.048	1816.45
31	0	1.880	1.054	1425.96
32	0	1.884	1.055	1507.34
33	0	1.889	1.056	1585.98
34	0	1.893	1.056	1662.12
35	0	1.898	1.057	1735.94
36	0	1.902	1.058	1807.63
37	0	1.877	1.065	1408.67
38	0	1.881	1.066	1489.76
39	0	1.886	1.067	1568.31
40	0	1.890	1.067	1644.49
41	0	1.895	1.068	1718.42
42	0	1.899	1.069	1790.21
43	0	1.876	1.070	1409.27
44	0	1.880	1.071	1490.06
45	0	1.885	1.072	1568.35
46	0	1.889	1.072	1644.31
47	0	1.894	1.073	1719.06
48	0	1.898	1.074	1789.77
49	0	1.875	1.075	1410.69
50	0	1.879	1.076	1488.71
51	0	1.883	1.077	1564.25
52	0	1.888	1.078	1637.56
53	0	1.892	1.079	1708.76
54	0	1.896	1.080	1776.01
55	0	1.873	1.084	1412.92
56	0	1.877	1.085	1488.37
57	0	1.881	1.086	1561.16
58	0	1.885	1.088	1631.73
59	0	1.889	1.089	1700.29
60	0	1.893	1.090	1766.96

PROGRAM F1240T STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE010 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
61	0	1.868	1.096	1384.41
62	0	1.872	1.098	1461.54
63	0	1.876	1.099	1535.99
64	0	1.880	1.101	1608.25
65	0	1.884	1.102	1678.47
66	0	1.888	1.104	1746.78
67	0	1.863	1.109	1369.59
68	0	1.867	1.111	1446.21
69	0	1.871	1.112	1520.22
70	0	1.875	1.114	1592.10
71	0	1.879	1.115	1661.93
72	0	1.883	1.117	1729.78
73	0	1.859	1.122	1378.66
74	0	1.863	1.124	1452.07
75	0	1.867	1.125	1522.38
76	0	1.870	1.127	1590.49
77	0	1.874	1.128	1656.58
78	0	1.878	1.130	1720.85
79	0	1.852	1.133	1336.58
80	0	1.856	1.135	1414.36
81	0	1.860	1.137	1487.01
82	0	1.863	1.139	1557.31
83	0	1.867	1.141	1625.45
84	0	1.871	1.143	1691.65
85	0	1.845	1.145	1316.12
86	0	1.849	1.147	1392.19
87	0	1.853	1.149	1465.43
88	0	1.856	1.152	1536.74
89	0	1.860	1.154	1605.26
90	0	1.864	1.156	1672.29
91	0	1.839	1.157	1315.11
92	0	1.842	1.159	1384.93
93	0	1.846	1.161	1451.90
94	0	1.849	1.164	1516.53
95	0	1.853	1.166	1579.43
96	0	1.856	1.168	1640.75
97	0	1.831	1.167	1277.75
98	0	1.834	1.170	1347.77
99	0	1.837	1.172	1414.90
100	0	1.841	1.175	1479.45
101	0	1.844	1.177	1542.07
102	0	1.847	1.180	1603.99
103	0	1.822	1.178	1244.82
104	0	1.825	1.181	1316.50
105	0	1.829	1.183	1385.53
106	0	1.832	1.186	1452.01
107	0	1.836	1.188	1516.29
108	0	1.839	1.191	1578.74
109	0	1.814	1.189	1232.73
110	0	1.817	1.192	1302.83
111	0	1.820	1.195	1370.04
112	0	1.824	1.197	1434.68
113	0	1.827	1.200	1497.08
114	0	1.830	1.203	1557.80
115	0	1.799	1.203	1168.64
116	0	1.802	1.206	1238.79
117	0	1.805	1.209	1306.23
118	0	1.808	1.213	1371.06
119	0	1.811	1.216	1433.47
120	0	1.814	1.219	1493.75

PROGRAM F[illegible]01 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE010 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
121	0	1.784	1.217	1122.77
122	0	1.787	1.220	1192.98
123	0	1.790	1.224	1260.53
124	0	1.793	1.227	1325.64
125	0	1.796	1.231	1388.49
126	0	1.799	1.234	1442.31
127	0	1.767	1.229	1050.08
128	0	1.770	1.233	1115.46
129	0	1.772	1.236	1178.60
130	0	1.775	1.240	1239.63
131	0	1.777	1.243	1298.58
132	0	1.780	1.247	1355.51
133	0	1.752	1.241	1010.34
134	0	1.754	1.245	1071.71
135	0	1.757	1.248	1130.67
136	0	1.759	1.252	1187.52
137	0	1.762	1.255	1242.57
138	0	1.764	1.259	1295.98
139	0	1.733	1.250	916.43
140	0	1.735	1.254	975.83
141	0	1.737	1.258	1032.73
142	0	1.739	1.262	1087.60
143	0	1.741	1.266	1140.10
144	0	1.743	1.270	1190.50
145	0	1.717	1.260	870.31
146	0	1.718	1.264	915.62
147	0	1.720	1.268	970.85
148	0	1.721	1.272	1016.33
149	0	1.723	1.276	1072.73
150	0	1.724	1.280	1119.80
151	0	1.724	1.288	1196.79
152	0	1.724	1.297	1276.43
153	0	1.724	1.305	1368.72
154	0	1.724	1.307	1374.38
155	0	1.724	1.308	1378.32
156	0	1.724	1.309	1380.63
157	0	1.724	1.311	1381.39
158	0	1.748	1.305	1939.96
159	0	1.748	1.307	1924.66
160	0	1.748	1.308	1913.92
161	0	1.748	1.309	1907.55
162	0	1.748	1.311	1905.44
163	0	1.703	1.000	228.03
164	0	1.703	1.059	226.85
165	0	1.703	1.119	223.57
166	0	1.703	1.178	208.81
167	0	1.680	1.273	607.59
168	0	1.681	1.277	643.81
169	0	1.682	1.281	677.72
170	0	1.683	1.286	709.30
171	0	1.684	1.290	738.61
172	0	1.685	1.294	765.40
173	0	1.686	1.298	783.15
174	0	1.687	1.301	797.86
175	0	1.688	1.305	808.59
176	0	1.688	1.307	810.16
177	0	1.688	1.308	811.30
178	0	1.688	1.309	812.00
179	0	1.688	1.311	812.23
180	0	1.663	1.000	259.28

PROGRAM F12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE010 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
181	0	1.663	1.059	287.03
182	0	1.663	1.119	247.77
183	0	1.663	1.178	222.05
184	0	1.631	1.000	281.41
185	0	1.631	1.059	278.65
186	0	1.631	1.119	268.38
187	0	1.631	1.178	236.91
188	0	1.640	1.282	371.48
189	0	1.641	1.287	392.05
190	0	1.641	1.291	409.09
191	0	1.642	1.296	422.70
192	0	1.642	1.300	432.89
193	0	1.643	1.305	439.73
194	0	1.643	1.307	440.84
195	0	1.643	1.308	441.62
196	0	1.643	1.309	443.09
197	0	1.643	1.311	442.25
198	0	1.600	1.000	301.51
199	0	1.600	1.069	297.83
200	0	1.600	1.139	233.49
201	0	1.600	1.208	248.41
202	0	1.600	1.277	274.61
203	0	1.600	1.283	256.19
204	0	1.600	1.288	225.47
205	0	1.600	1.294	302.35
206	0	1.600	1.299	306.63
207	0	1.600	1.305	308.07
208	0	1.600	1.307	308.72
209	0	1.600	1.308	309.18
210	0	1.600	1.309	309.46
211	0	1.600	1.311	309.55
212	0	1.610	1.284	295.39
213	0	1.608	1.288	302.39
214	0	1.607	1.292	307.15
215	0	1.605	1.296	309.97
216	0	1.603	1.300	311.20
217	0	1.560	1.000	325.57
218	0	1.560	1.069	322.50
219	0	1.560	1.139	312.34
220	0	1.560	1.208	300.04
221	0	1.560	1.277	311.13
222	0	1.560	1.283	311.36
223	0	1.560	1.288	311.89
224	0	1.560	1.294	312.54
225	0	1.560	1.299	313.18
226	0	1.560	1.305	313.79
227	0	1.560	1.307	313.82
228	0	1.560	1.308	313.84
229	0	1.560	1.309	313.85
230	0	1.560	1.311	313.85
231	0	1.520	1.000	347.71
232	0	1.520	1.069	345.54
233	0	1.520	1.139	339.62
234	0	1.520	1.208	334.52
235	0	1.520	1.277	336.37
236	0	1.520	1.283	336.57
237	0	1.520	1.288	336.69
238	0	1.520	1.294	336.75
239	0	1.520	1.299	336.78
240	0	1.520	1.305	336.77

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM EI[illegible]01 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE010 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
241	0	1.520	1.307	336.78
242	0	1.520	1.308	316.79
243	0	1.520	1.309	336.79
244	0	1.520	1.311	336.79
245	0	1.498	1.277	349.51
246	0	1.498	1.283	349.44
247	0	1.498	1.288	349.39
248	0	1.498	1.294	349.35
249	0	1.498	1.299	349.32
250	0	1.498	1.305	349.31
251	0	1.498	1.307	349.30
252	0	1.498	1.308	349.30
253	0	1.498	1.309	349.30
254	0	1.498	1.311	349.30
255	0	1.480	1.000	367.82
256	0	1.480	1.078	356.10
257	0	1.480	1.156	362.25
258	0	1.480	1.233	360.20
259	0	1.480	1.311	359.89
260	0	1.400	1.000	401.81
261	0	1.400	1.078	401.26
262	0	1.400	1.156	400.04
263	0	1.400	1.233	399.01
264	0	1.400	1.311	398.65
265	0	1.200	1.000	446.32
266	0	1.200	1.078	446.29
267	0	1.200	1.156	446.20
268	0	1.200	1.233	446.09
269	0	1.200	1.311	446.04
270	0	1.000	1.000	431.43
271	0	1.000	1.078	431.43
272	0	1.000	1.156	431.41
273	0	1.000	1.233	431.39
274	0	1.000	1.311	431.38

PROGRAM [illegible]401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE011 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
1	0	1.563	1.000	1236.74
2	0	1.566	1.000	1433.25
3	0	1.568	1.000	1610.62
4	0	1.571	1.000	1775.01
5	0	1.573	1.000	1928.45
6	0	1.575	1.000	2072.49
7	0	1.562	1.010	1218.53
8	0	1.565	1.010	1415.80
9	0	1.567	1.011	1593.75
10	0	1.570	1.011	1759.09
11	0	1.572	1.012	1913.69
12	0	1.575	1.012	2059.04
13	0	1.559	1.020	1157.99
14	0	1.562	1.021	1358.85
15	0	1.564	1.022	1540.31
16	0	1.567	1.022	1709.23
17	0	1.569	1.023	1957.41
18	0	1.572	1.024	2016.24
19	0	1.556	1.029	1154.24
20	0	1.558	1.030	1348.03
21	0	1.561	1.031	1522.32
22	0	1.563	1.033	1693.91
23	0	1.566	1.034	1835.29
24	0	1.568	1.035	1977.85
25	0	1.551	1.038	1029.41
26	0	1.553	1.039	1296.00
27	0	1.556	1.041	1472.94
28	0	1.558	1.042	1635.72
29	0	1.561	1.044	1789.18
30	0	1.563	1.045	1931.68
31	0	1.545	1.046	1037.93
32	0	1.547	1.048	1213.91
33	0	1.549	1.050	1384.73
34	0	1.551	1.051	1535.49
35	0	1.553	1.053	1676.73
36	0	1.555	1.055	1810.12
37	0	1.538	1.053	957.78
38	0	1.540	1.055	1131.11
39	0	1.542	1.057	1298.78
40	0	1.543	1.059	1433.46
41	0	1.545	1.061	1567.80
42	0	1.547	1.063	1694.37
43	0	1.530	1.059	852.89
44	0	1.531	1.061	1007.68
45	0	1.533	1.063	1149.67
46	0	1.534	1.066	1282.08
47	0	1.536	1.068	1406.64
48	0	1.537	1.070	1525.41
49	0	1.535	1.075	1597.65
50	0	1.534	1.079	1662.86
51	0	1.532	1.084	1764.90
52	0	1.532	1.086	1774.33
53	0	1.532	1.087	1777.08
54	0	1.532	1.088	1777.49
55	0	1.532	1.090	1777.46
56	0	1.538	1.084	2165.83
57	0	1.538	1.086	2107.15
58	0	1.538	1.087	2073.10
59	0	1.538	1.088	2055.35
60	0	1.538	1.090	2049.84

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM E12401   STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE011   5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
61	0	1.521	1.064	707.36
62	0	1.522	1.066	846.09
63	0	1.523	1.069	974.46
64	0	1.525	1.071	1094.79
65	0	1.526	1.074	1209.30
66	0	1.527	1.076	1319.62
67	0	1.527	1.079	1384.34
68	0	1.527	1.081	1442.29
69	0	1.527	1.084	1481.45
70	0	1.527	1.086	1499.43
71	0	1.527	1.087	1511.74
72	0	1.527	1.088	1518.85
73	0	1.527	1.090	1521.16
74	0	1.512	1.068	554.12
75	0	1.513	1.070	651.13
76	0	1.513	1.073	737.36
77	0	1.514	1.075	814.31
78	0	1.514	1.078	882.95
79	0	1.515	1.080	943.83
80	0	1.515	1.081	960.00
81	0	1.515	1.083	973.63
82	0	1.515	1.084	986.05
83	0	1.515	1.086	997.98
84	0	1.515	1.087	1006.61
85	0	1.515	1.088	1011.85
86	0	1.515	1.090	1013.61
87	0	1.502	1.070	376.73
88	0	1.502	1.073	451.92
89	0	1.502	1.076	513.57
90	0	1.503	1.078	563.20
91	0	1.503	1.081	602.12
92	0	1.503	1.084	630.74
93	0	1.503	1.086	640.21
94	0	1.503	1.087	646.93
95	0	1.503	1.088	650.95
96	0	1.503	1.090	652.29
97	0	1.491	1.071	251.27
98	0	1.491	1.074	295.81
99	0	1.491	1.076	331.74
100	0	1.491	1.079	360.92
101	0	1.491	1.081	383.69
102	0	1.491	1.084	400.43
103	0	1.491	1.086	407.35
104	0	1.491	1.087	412.29
105	0	1.491	1.088	415.25
106	0	1.491	1.090	416.23
107	0	1.479	1.071	179.49
108	0	1.479	1.074	204.61
109	0	1.479	1.076	225.47
110	0	1.479	1.079	242.71
111	0	1.479	1.081	256.34
112	0	1.479	1.084	265.37
113	0	1.479	1.086	270.52
114	0	1.479	1.087	273.48
115	0	1.479	1.088	275.26
116	0	1.479	1.090	275.85
117	0	1.459	1.071	125.57
118	0	1.459	1.074	135.52
119	0	1.459	1.076	144.03
120	0	1.459	1.079	151.05

PROGRAM E12401   STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE011   5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
121	0	1.459	1.081	156.61
122	0	1.459	1.084	160.71
123	0	1.459	1.086	162.42
124	0	1.459	1.087	163.64
125	0	1.459	1.088	164.37
126	0	1.459	1.090	164.62
127	0	1.439	1.071	120.09
128	0	1.439	1.074	121.88
129	0	1.439	1.076	123.63
130	0	1.439	1.079	125.23
131	0	1.439	1.081	126.59
132	0	1.439	1.084	127.65
133	0	1.439	1.086	128.09
134	0	1.439	1.087	128.42
135	0	1.439	1.088	128.61
136	0	1.439	1.090	128.68
137	0	1.419	1.071	116.33
138	0	1.419	1.074	117.05
139	0	1.419	1.076	117.66
140	0	1.419	1.079	118.16
141	0	1.419	1.081	118.56
142	0	1.419	1.084	118.86
143	0	1.419	1.086	118.99
144	0	1.419	1.087	119.07
145	0	1.419	1.088	119.13
146	0	1.419	1.090	119.14
147	0	1.400	1.072	116.45
148	0	1.400	1.075	116.58
149	0	1.400	1.077	116.70
150	0	1.400	1.080	116.82
151	0	1.400	1.082	116.91
152	0	1.400	1.085	116.99
153	0	1.400	1.087	117.02
154	0	1.400	1.088	117.04
155	0	1.400	1.090	117.05
156	0	1.400	1.091	117.05
157	0	1.380	1.072	116.04
158	0	1.380	1.075	116.18
159	0	1.380	1.077	116.29
160	0	1.380	1.080	116.37
161	0	1.380	1.082	116.44
162	0	1.380	1.085	116.49
163	0	1.380	1.087	116.51
164	0	1.380	1.088	116.53
165	0	1.380	1.090	116.54
166	0	1.380	1.091	116.54
167	0	1.360	1.073	116.30
168	0	1.360	1.075	116.36
169	0	1.360	1.078	116.42
170	0	1.360	1.080	116.48
171	0	1.360	1.083	116.53
172	0	1.360	1.085	116.58
173	0	1.360	1.087	116.59
174	0	1.360	1.088	116.61
175	0	1.360	1.090	116.62
176	0	1.360	1.091	116.62
177	0	1.337	1.073	116.17
178	0	1.337	1.075	116.61
179	0	1.337	1.078	116.98
180	0	1.337	1.080	117.29

PROGRAM 12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE011 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
181	0	1.337	1.083	117.54
182	0	1.337	1.085	117.74
183	0	1.337	1.087	117.83
184	0	1.337	1.088	117.90
185	0	1.337	1.090	117.95
186	0	1.337	1.091	117.97
187	0	1.313	1.000	118.17
188	0	1.313	1.030	116.85
189	0	1.313	1.059	119.26
190	0	1.313	1.064	120.69
191	0	1.313	1.070	121.79
192	0	1.313	1.075	122.60
193	0	1.313	1.081	123.15
194	0	1.313	1.086	123.50
195	0	1.313	1.088	123.56
196	0	1.313	1.089	123.60
197	0	1.313	1.090	123.63
198	0	1.313	1.092	123.64
199	0	1.293	1.000	128.31
200	0	1.293	1.030	128.38
201	0	1.293	1.059	129.48
202	0	1.293	1.064	129.61
203	0	1.293	1.070	129.80
204	0	1.293	1.075	129.99
205	0	1.293	1.081	130.15
206	0	1.293	1.086	130.25
207	0	1.293	1.088	130.27
208	0	1.293	1.089	130.28
209	0	1.293	1.090	130.29
210	0	1.293	1.092	130.29
211	0	1.253	1.000	144.53
212	0	1.253	1.030	144.51
213	0	1.253	1.059	144.32
214	0	1.253	1.064	144.29
215	0	1.253	1.070	144.25
216	0	1.253	1.075	144.22
217	0	1.253	1.081	144.20
218	0	1.253	1.086	144.18
219	0	1.253	1.088	144.18
220	0	1.253	1.089	144.18
221	0	1.253	1.090	144.18
222	0	1.253	1.092	144.18
223	0	1.212	1.000	156.79
224	0	1.212	1.030	156.64
225	0	1.212	1.059	156.10
226	0	1.212	1.064	155.93
227	0	1.212	1.070	155.82
228	0	1.212	1.075	155.74
229	0	1.212	1.081	155.69
230	0	1.212	1.086	155.66
231	0	1.212	1.088	155.66
232	0	1.212	1.089	155.65
233	0	1.212	1.090	155.66
234	0	1.212	1.092	155.66
235	0	1.151	1.000	170.11
236	0	1.151	1.031	170.09
237	0	1.151	1.062	170.09
238	0	1.151	1.093	170.24
239	0	1.100	1.000	177.60
240	0	1.100	1.031	177.61

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

MAX FLUX TUBE SECT. STA.22 SKETCH 4261-09-033 2KFE011 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 7

N.P. NO.	CODE	X	Y	T
241	0	1.100	1.062	177.62
242	0	1.100	1.093	177.61
243	0	1.000	1.000	183.29
244	0	1.000	1.031	183.29
245	0	1.000	1.062	183.29
246	0	1.000	1.093	183.29

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE012 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
1	0	1.885	1.000	1283.80
2	0	1.890	1.000	1364.64
3	0	1.894	1.000	1441.93
4	0	1.899	1.000	1515.20
5	0	1.903	1.000	1588.22
6	0	1.908	1.000	1658.20
7	0	1.885	1.010	1286.38
8	0	1.889	1.010	1363.76
9	0	1.894	1.010	1437.83
10	0	1.898	1.011	1509.03
11	0	1.903	1.011	1578.11
12	0	1.907	1.011	1645.19
13	0	1.884	1.023	1280.16
14	0	1.888	1.023	1357.71
15	0	1.893	1.024	1431.99
16	0	1.897	1.024	1503.37
17	0	1.902	1.025	1572.62
18	0	1.906	1.025	1639.89
19	0	1.883	1.034	1278.84
20	0	1.887	1.034	1356.30
21	0	1.892	1.035	1430.49
22	0	1.896	1.035	1501.74
23	0	1.901	1.036	1570.85
24	0	1.905	1.036	1637.92
25	0	1.882	1.044	1281.39
26	0	1.886	1.045	1359.51
27	0	1.891	1.046	1434.32
28	0	1.895	1.046	1506.01
29	0	1.900	1.047	1575.50
30	0	1.904	1.048	1642.95
31	0	1.880	1.054	1272.69
32	0	1.884	1.055	1350.66
33	0	1.889	1.056	1425.51
34	0	1.893	1.056	1497.33
35	0	1.898	1.057	1565.88
36	0	1.902	1.058	1634.45
37	0	1.877	1.065	1255.11
38	0	1.881	1.066	1334.01
39	0	1.886	1.067	1408.76
40	0	1.890	1.067	1480.57
41	0	1.895	1.068	1550.18
42	0	1.899	1.069	1617.79
43	0	1.876	1.070	1255.56
44	0	1.880	1.071	1334.24
45	0	1.885	1.072	1408.73
46	0	1.889	1.072	1480.34
47	0	1.894	1.073	1549.74
48	0	1.898	1.074	1617.25
49	0	1.875	1.075	1257.97
50	0	1.879	1.076	1332.88
51	0	1.883	1.077	1404.77
52	0	1.888	1.078	1473.39
53	0	1.892	1.079	1540.93
54	0	1.896	1.080	1605.04
55	0	1.873	1.084	1260.06
56	0	1.877	1.085	1332.45
57	0	1.881	1.086	1401.72
58	0	1.885	1.088	1468.27
59	0	1.889	1.089	1532.70
60	0	1.893	1.090	1595.38

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM EI-01 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

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STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
61	0	1.868	1.096	1232.86
62	0	1.872	1.098	1306.78
63	0	1.876	1.099	1377.73
64	0	1.880	1.101	1445.96
65	0	1.884	1.102	1511.87
66	0	1.888	1.104	1576.02
67	0	1.863	1.109	1218.71
68	0	1.867	1.111	1292.07
69	0	1.871	1.112	1362.65
70	0	1.875	1.114	1430.59
71	0	1.879	1.115	1496.06
72	0	1.883	1.117	1559.59
73	0	1.859	1.122	1227.38
74	0	1.863	1.124	1297.58
75	0	1.867	1.125	1364.53
76	0	1.870	1.127	1429.95
77	0	1.874	1.128	1490.38
78	0	1.878	1.130	1551.06
79	0	1.852	1.133	1189.47
80	0	1.856	1.135	1261.74
81	0	1.860	1.137	1331.07
82	0	1.863	1.139	1397.51
83	0	1.867	1.141	1461.59
84	0	1.871	1.143	1523.49
85	0	1.845	1.145	1168.39
86	0	1.849	1.147	1240.76
87	0	1.853	1.149	1310.57
88	0	1.856	1.152	1377.77
89	0	1.860	1.154	1442.52
90	0	1.864	1.156	1505.09
91	0	1.839	1.157	1167.58
92	0	1.842	1.159	1234.00
93	0	1.846	1.161	1297.71
94	0	1.849	1.164	1359.01
95	0	1.853	1.166	1418.17
96	0	1.856	1.168	1475.39
97	0	1.831	1.167	1132.78
98	0	1.834	1.170	1199.06
99	0	1.837	1.172	1262.74
100	0	1.841	1.175	1324.00
101	0	1.844	1.177	1383.01
102	0	1.847	1.180	1439.95
103	0	1.822	1.178	1102.32
104	0	1.825	1.181	1169.95
105	0	1.829	1.183	1235.23
106	0	1.832	1.186	1298.20
107	0	1.836	1.188	1358.86
108	0	1.839	1.191	1417.32
109	0	1.814	1.189	1091.76
110	0	1.817	1.192	1157.69
111	0	1.820	1.195	1221.02
112	0	1.824	1.197	1282.05
113	0	1.827	1.200	1340.93
114	0	1.830	1.203	1397.86
115	0	1.799	1.203	1033.06
116	0	1.802	1.206	1098.81
117	0	1.805	1.209	1162.03
118	0	1.808	1.213	1222.94
119	0	1.811	1.216	1281.56
120	0	1.814	1.219	1338.26

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE012 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
121	0	1.784	1.217	992.26
122	0	1.787	1.220	1057.81
123	0	1.790	1.224	1120.78
124	0	1.793	1.227	1181.52
125	0	1.796	1.231	1240.28
126	0	1.799	1.234	1297.24
127	0	1.767	1.229	925.95
128	0	1.770	1.233	987.89
129	0	1.772	1.236	1046.56
130	0	1.775	1.240	1103.16
131	0	1.777	1.243	1157.96
132	0	1.780	1.247	1210.77
133	0	1.752	1.241	893.31
134	0	1.754	1.245	950.22
135	0	1.757	1.248	1004.79
136	0	1.759	1.252	1057.24
137	0	1.762	1.255	1107.92
138	0	1.764	1.259	1157.07
139	0	1.733	1.250	811.58
140	0	1.735	1.254	866.52
141	0	1.737	1.258	919.09
142	0	1.739	1.262	969.53
143	0	1.741	1.266	1017.75
144	0	1.743	1.270	1063.59
145	0	1.717	1.260	775.38
146	0	1.718	1.264	819.20
147	0	1.720	1.268	868.94
148	0	1.721	1.272	911.13
149	0	1.723	1.276	953.21
150	0	1.724	1.280	1007.15
151	0	1.724	1.288	1080.51
152	0	1.724	1.297	1156.44
153	0	1.724	1.305	1243.82
154	0	1.724	1.307	1249.20
155	0	1.724	1.308	1252.94
156	0	1.724	1.309	1255.14
157	0	1.724	1.311	1255.37
158	0	1.748	1.305	1773.75
159	0	1.748	1.307	1759.60
160	0	1.749	1.308	1749.57
161	0	1.748	1.309	1743.78
162	0	1.748	1.311	1741.83
163	0	1.703	1.000	235.49
164	0	1.703	1.059	234.35
165	0	1.703	1.119	231.25
166	0	1.703	1.178	217.21
167	0	1.680	1.273	550.32
168	0	1.681	1.277	593.06
169	0	1.682	1.281	613.74
170	0	1.683	1.286	642.36
171	0	1.684	1.290	669.96
172	0	1.685	1.294	693.34
173	0	1.686	1.298	709.29
174	0	1.687	1.301	722.44
175	0	1.688	1.305	731.93
176	0	1.688	1.307	733.38
177	0	1.688	1.308	734.44
178	0	1.688	1.309	735.08
179	0	1.688	1.311	735.30
180	0	1.663	1.000	265.58

PROGRAM F 401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE012 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
181	0	1.663	1.059	263.38
182	0	1.663	1.119	254.42
183	0	1.663	1.178	229.76
184	0	1.631	1.000	287.10
185	0	1.631	1.059	284.37
186	0	1.631	1.119	274.31
187	0	1.631	1.178	243.80
188	0	1.640	1.282	349.29
189	0	1.641	1.297	367.27
190	0	1.641	1.291	382.34
191	0	1.642	1.296	394.26
192	0	1.642	1.300	403.15
193	0	1.643	1.305	409.05
194	0	1.643	1.307	410.03
195	0	1.643	1.308	410.73
196	0	1.643	1.309	411.15
197	0	1.643	1.311	411.29
198	0	1.600	1.000	306.68
199	0	1.600	1.059	303.04
200	0	1.600	1.139	288.37
201	0	1.600	1.208	254.94
202	0	1.600	1.277	274.10
203	0	1.600	1.283	283.75
204	0	1.600	1.288	291.53
205	0	1.600	1.294	297.32
206	0	1.600	1.299	300.92
207	0	1.600	1.305	302.10
208	0	1.600	1.307	302.65
209	0	1.600	1.308	303.04
210	0	1.600	1.309	303.28
211	0	1.600	1.311	303.36
212	0	1.610	1.284	289.47
213	0	1.608	1.288	295.92
214	0	1.607	1.292	300.22
215	0	1.605	1.296	302.95
216	0	1.603	1.300	304.29
217	0	1.560	1.000	330.13
218	0	1.560	1.069	327.05
219	0	1.560	1.139	316.99
220	0	1.560	1.208	304.00
221	0	1.560	1.277	311.42
222	0	1.560	1.283	311.54
223	0	1.560	1.288	311.92
224	0	1.560	1.294	312.41
225	0	1.560	1.299	312.92
226	0	1.560	1.305	313.41
227	0	1.560	1.307	313.43
228	0	1.560	1.308	313.44
229	0	1.560	1.309	313.45
230	0	1.560	1.311	313.46
231	0	1.520	1.000	351.76
232	0	1.520	1.069	349.55
233	0	1.520	1.139	343.45
234	0	1.520	1.208	337.59
235	0	1.520	1.277	337.98
236	0	1.520	1.283	338.00
237	0	1.520	1.288	338.05
238	0	1.520	1.294	338.07
239	0	1.520	1.299	338.07
240	0	1.520	1.305	338.04

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE012 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 6

N.P. NO.	CODE	X	Y	T
241	0	1.520	1.307	338.04
242	0	1.520	1.308	339.05
243	0	1.520	1.309	338.05
244	0	1.520	1.311	338.05
245	0	1.498	1.277	351.42
246	0	1.498	1.283	351.30
247	0	1.498	1.288	351.20
248	0	1.498	1.294	351.12
249	0	1.498	1.299	351.05
250	0	1.498	1.305	351.02
251	0	1.498	1.307	351.01
252	0	1.498	1.308	351.00
253	0	1.498	1.309	351.00
254	0	1.498	1.311	351.00
255	0	1.480	1.000	371.46
256	0	1.480	1.078	369.56
257	0	1.480	1.156	365.50
258	0	1.480	1.233	362.68
259	0	1.480	1.311	361.77
260	0	1.400	1.000	404.90
261	0	1.400	1.078	404.27
262	0	1.400	1.156	402.36
263	0	1.400	1.233	401.58
264	0	1.400	1.311	401.09
265	0	1.200	1.000	448.76
266	0	1.200	1.078	448.72
267	0	1.200	1.156	446.59
268	0	1.200	1.233	449.48
269	0	1.200	1.311	448.42
270	0	1.000	1.000	433.62
271	0	1.000	1.078	433.51
272	0	1.000	1.156	433.58
273	0	1.000	1.233	433.56
274	0	1.000	1.311	433.56

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KEE013 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 5

N.P. NO.	CODE	X	Y	T
1	0	1.885	1.000	1520.61
2	0	1.890	1.000	1610.21
3	0	1.894	1.000	1696.73
4	0	1.899	1.000	1739.40
5	0	1.903	1.000	1861.44
6	0	1.908	1.000	1940.09
7	0	1.885	1.010	1523.47
8	0	1.889	1.010	1609.24
9	0	1.894	1.010	1692.13
10	0	1.898	1.011	1772.35
11	0	1.903	1.011	1850.11
12	0	1.907	1.011	1925.54
13	0	1.884	1.023	1516.59
14	0	1.888	1.023	1602.52
15	0	1.893	1.024	1685.62
16	0	1.897	1.024	1766.07
17	0	1.902	1.025	1844.06
18	0	1.906	1.025	1919.74
19	0	1.883	1.034	1515.15
20	0	1.887	1.034	1600.99
21	0	1.892	1.035	1687.98
22	0	1.896	1.035	1764.31
23	0	1.901	1.036	1842.13
24	0	1.905	1.036	1917.61
25	0	1.882	1.044	1518.02
26	0	1.886	1.045	1604.71
27	0	1.891	1.046	1688.33
28	0	1.895	1.046	1769.17
29	0	1.900	1.047	1847.44
30	0	1.904	1.048	1923.33
31	0	1.880	1.054	1508.37
32	0	1.884	1.055	1594.97
33	0	1.889	1.056	1678.58
34	0	1.893	1.056	1759.47
35	0	1.898	1.057	1837.85
36	0	1.902	1.058	1913.91
37	0	1.877	1.065	1490.00
38	0	1.881	1.066	1576.23
39	0	1.886	1.067	1659.76
40	0	1.890	1.067	1740.71
41	0	1.895	1.068	1819.22
42	0	1.899	1.069	1895.40
43	0	1.876	1.070	1490.65
44	0	1.880	1.071	1576.53
45	0	1.885	1.072	1659.79
46	0	1.889	1.072	1740.51
47	0	1.894	1.073	1818.83
48	0	1.898	1.074	1894.93
49	0	1.875	1.075	1492.14
50	0	1.879	1.076	1575.07
51	0	1.883	1.077	1655.41
52	0	1.888	1.078	1733.21
53	0	1.892	1.079	1808.94
54	0	1.896	1.080	1882.45
55	0	1.873	1.084	1494.52
56	0	1.877	1.085	1574.65
57	0	1.881	1.086	1652.07
58	0	1.885	1.088	1727.07
59	0	1.889	1.089	1799.89
60	0	1.893	1.090	1870.66

PROGRAM E12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KEE013 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 5

N.P. NO.	CODE	X	Y	T
61	0	1.868	1.096	1464.71
62	0	1.872	1.098	1546.04
63	0	1.876	1.099	1625.23
64	0	1.880	1.101	1702.04
65	0	1.884	1.102	1776.62
66	0	1.888	1.104	1849.13
67	0	1.863	1.109	1448.61
68	0	1.867	1.111	1529.67
69	0	1.871	1.112	1609.40
70	0	1.875	1.114	1684.81
71	0	1.879	1.115	1758.99
72	0	1.883	1.117	1831.02
73	0	1.859	1.122	1459.19
74	0	1.863	1.124	1535.79
75	0	1.867	1.125	1610.62
76	0	1.870	1.127	1693.02
77	0	1.874	1.128	1753.24
78	0	1.878	1.130	1821.48
79	0	1.852	1.133	1415.82
80	0	1.856	1.135	1495.74
81	0	1.860	1.137	1572.95
82	0	1.863	1.139	1647.71
83	0	1.867	1.141	1720.15
84	0	1.871	1.143	1790.42
85	0	1.845	1.145	1392.11
86	0	1.849	1.147	1472.27
87	0	1.853	1.149	1549.95
88	0	1.856	1.152	1625.77
89	0	1.860	1.154	1698.63
90	0	1.864	1.156	1762.84
91	0	1.839	1.157	1390.99
92	0	1.842	1.159	1464.60
93	0	1.846	1.161	1535.47
94	0	1.849	1.164	1604.25
95	0	1.853	1.166	1671.14
96	0	1.856	1.168	1736.31
97	0	1.831	1.167	1351.51
98	0	1.834	1.170	1425.73
99	0	1.837	1.172	1496.15
100	0	1.841	1.175	1564.74
101	0	1.844	1.177	1631.33
102	0	1.847	1.180	1696.08
103	0	1.822	1.178	1316.70
104	0	1.825	1.181	1392.30
105	0	1.829	1.183	1465.04
106	0	1.832	1.186	1535.45
107	0	1.836	1.188	1603.82
108	0	1.839	1.191	1670.21
109	0	1.814	1.189	1303.90
110	0	1.817	1.192	1377.88
111	0	1.820	1.195	1448.73
112	0	1.824	1.197	1516.94
113	0	1.827	1.200	1583.23
114	0	1.830	1.203	1647.77
115	0	1.799	1.203	1236.26
116	0	1.802	1.206	1310.44
117	0	1.805	1.209	1381.56
118	0	1.808	1.213	1449.85
119	0	1.811	1.216	1515.77
120	0	1.814	1.219	1579.83

AEROJET-GENERAL CORPORATION
SACRAMENTO, CALIFORNIA

PROGRAM F12401 STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KFE013 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 5

N.P. NO.	CODE	X	Y	T
121	0	1.784	1.217	1188.15
122	0	1.787	1.220	1262.51
123	0	1.790	1.224	1333.88
124	0	1.793	1.227	1402.49
125	0	1.795	1.231	1468.62
126	0	1.799	1.234	1532.82
127	0	1.767	1.229	1112.11
128	0	1.770	1.233	1191.46
129	0	1.772	1.236	1268.32
130	0	1.775	1.240	1312.94
131	0	1.777	1.243	1375.17
132	0	1.780	1.247	1435.16
133	0	1.752	1.241	1071.01
134	0	1.754	1.245	1136.13
135	0	1.757	1.248	1198.77
136	0	1.759	1.252	1259.09
137	0	1.762	1.255	1317.46
138	0	1.764	1.259	1374.05
139	0	1.733	1.250	972.26
140	0	1.735	1.254	1035.28
141	0	1.737	1.258	1095.69
142	0	1.739	1.262	1153.98
143	0	1.741	1.266	1209.76
144	0	1.743	1.270	1263.25
145	0	1.717	1.260	927.63
146	0	1.718	1.264	971.91
147	0	1.720	1.268	1030.66
148	0	1.721	1.272	1079.00
149	0	1.723	1.276	1138.90
150	0	1.724	1.280	1198.90
151	0	1.724	1.288	1270.61
152	0	1.724	1.297	1355.10
153	0	1.724	1.305	1453.09
154	0	1.724	1.307	1459.11
155	0	1.724	1.308	1463.29
156	0	1.724	1.309	1465.74
157	0	1.724	1.311	1466.55
158	0	1.748	1.305	2060.59
159	0	1.748	1.307	2044.31
160	0	1.748	1.308	2032.89
161	0	1.748	1.309	2026.12
162	0	1.748	1.311	2023.87
163	0	1.703	1.000	240.75
164	0	1.703	1.059	239.69
165	0	1.703	1.119	236.41
166	0	1.703	1.178	222.17
167	0	1.680	1.273	644.66
168	0	1.681	1.277	693.38
169	0	1.682	1.281	719.58
170	0	1.683	1.286	753.24
171	0	1.684	1.290	784.43
172	0	1.685	1.294	812.93
173	0	1.686	1.298	831.92
174	0	1.687	1.301	847.46
175	0	1.688	1.305	858.87
176	0	1.688	1.307	860.53
177	0	1.688	1.308	861.75
178	0	1.688	1.309	862.49
179	0	1.688	1.311	862.74
180	0	1.663	1.000	270.76

PROGRAM 312A STEADY-STATE HEAT TRANSFER ANALYSIS OF A TWO-DIMENSIONAL BODY

BARREL TUBE SECT. STA.35 SKETCH 4261-09-033 2KEF013 5 APR 71

STEADY-STATE TEMPERATURES

ITERATION NO. 5

N.P. NO.	CODE	X	Y	T
181	0	1.663	1.059	268.57
182	0	1.663	1.119	259.63
183	0	1.663	1.178	234.96
184	0	1.631	1.000	292.38
185	0	1.631	1.059	289.71
186	0	1.631	1.119	279.68
187	0	1.631	1.178	249.26
188	0	1.640	1.232	393.24
189	0	1.641	1.287	415.09
190	0	1.641	1.291	433.19
191	0	1.642	1.296	447.65
192	0	1.642	1.300	458.48
193	0	1.643	1.305	465.77
194	0	1.643	1.307	466.94
195	0	1.643	1.308	467.77
196	0	1.643	1.309	468.27
197	0	1.643	1.311	468.43
198	0	1.600	1.000	312.07
199	0	1.600	1.069	309.49
200	0	1.600	1.139	294.60
201	0	1.600	1.208	260.36
202	0	1.600	1.277	298.63
203	0	1.600	1.283	300.81
204	0	1.600	1.289	310.59
205	0	1.600	1.294	317.84
206	0	1.600	1.299	322.34
207	0	1.600	1.305	323.85
208	0	1.600	1.307	324.53
209	0	1.600	1.308	325.03
210	0	1.600	1.309	325.31
211	0	1.600	1.311	325.41
212	0	1.610	1.284	311.37
213	0	1.608	1.268	318.58
214	0	1.607	1.292	323.43
215	0	1.605	1.296	326.26
216	0	1.603	1.300	327.39
217	0	1.560	1.000	335.65
218	0	1.560	1.069	332.68
219	0	1.560	1.139	322.87
220	0	1.560	1.208	311.29
221	0	1.560	1.277	323.69
222	0	1.560	1.283	323.98
223	0	1.560	1.288	324.53
224	0	1.560	1.294	325.29
225	0	1.560	1.299	325.98
226	0	1.560	1.305	326.64
227	0	1.560	1.307	326.67
228	0	1.560	1.308	326.69
229	0	1.560	1.309	326.70
230	0	1.560	1.311	326.71
231	0	1.520	1.000	357.36
232	0	1.520	1.069	355.28
233	0	1.520	1.139	349.65
234	0	1.520	1.208	345.10
235	0	1.520	1.277	347.64
236	0	1.520	1.283	347.82
237	0	1.520	1.288	348.03
238	0	1.520	1.294	348.13
239	0	1.520	1.299	348.17
240	0	1.520	1.305	348.17

STEADY-STATE TEMPERATURES

ITERATION NO. 5

N.P. NO.	CODE	X	Y	T
241	0	1.520	1.307	348.19
242	0	1.520	1.308	348.19
243	0	1.520	1.309	348.20
244	0	1.520	1.311	348.20
245	0	1.498	1.277	360.22
246	0	1.498	1.283	360.19
247	0	1.498	1.288	360.17
248	0	1.498	1.294	360.17
249	0	1.498	1.299	360.16
250	0	1.498	1.305	360.17
251	0	1.498	1.307	360.17
252	0	1.498	1.308	360.16
253	0	1.498	1.309	360.16
254	0	1.498	1.311	360.16
255	0	1.480	1.000	377.19
256	0	1.480	1.078	375.57
257	0	1.480	1.156	371.93
258	0	1.480	1.233	370.30
259	0	1.480	1.311	370.35
260	0	1.400	1.000	410.69
261	0	1.400	1.078	410.18
262	0	1.400	1.156	409.09
263	0	1.400	1.233	408.22
264	0	1.400	1.311	407.93
265	0	1.200	1.000	454.13
266	0	1.200	1.078	454.10
267	0	1.200	1.156	454.02
268	0	1.200	1.233	453.93
269	0	1.200	1.311	453.88
270	0	1.000	1.000	438.51
271	0	1.000	1.078	438.51
272	0	1.000	1.156	438.49
273	0	1.000	1.233	438.47
274	0	1.000	1.311	438.47

APPENDIX D

NOZZLE TUBE STRESS ANALYSIS

MAXIMUM FLUX AND BARREL SECTION

i

AEROJET NUCLEAR SYSTEMS COMPANY

SACRAMENTO, CALIFORNIA

TO: L. A. Shurley

19 November 1971
JLP:jh N8120:099

FROM: U. A. Pineda

SUBJECT: Thermal Strain Analysis of the Nozzle Tubes Operating in the Steady State Condition

DISTRIBUTION: J. L. Pickering, K. Sato, J. L. Watkins

ENCLOSURE: (1) ANSC Report N8120:71-015, "75K Nozzle U-Tube Strain Analysis Operating Under the Steady State Condition"

This report represents partial fulfillment to Work Statement 8 for the predicting of the coolant-channel cyclic life. The strain magnitudes developed in this report will be compared with the low-cycle fatigue data developed in Phase I and Phase II test programs.

U. A. Pineda

U. A. Pineda, Supervisor
Applied Mechanics Section
Engineering Staff Department

CLASSIFICATION CATEGORY
Unclassified
[signature] 11/12/71
CLASSIFYING OFFICER DATE

ENCLOSURE (1)

N8120R:71-015

ENGINEERING OPERATIONS REPORT

NERVA
75K NOZZLE U-TUBE STRAIN
ANALYSIS OPERATING UNDER THE
STEADY STATE CONDITION

PROJECT 141

8 NOVEMBER 1971

J. L. Pickering

J. L. Pickering

iii

APPROVED:

K. Sato

K. Sato, Manager
Engineering Staff Department

CLASSIFICATION CATEGORY
Unclassified
[illegible] 11-22-71
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TABLE OF CONTENTS

I. LIST OF REFERENCES

1. Memo N4320:M1671, E. A. Thomas to J. L. Watkins, dated 4-15-71, subject: "NERVA 75K Coolant Channel Steady State Temperature Distributions for $T_c = 4568^{\circ}$ and $4318^{\circ}R$ with Minimum Nuclear Heating Rates"

2. Memo N8110:M1679, J. J. Williams to J. L. Watkins, dated 4-19-71, subject: "Steady State Temperature Distributions in the NERVA Nozzle Coolant Channels with a 300 Degree Increase in Nominal Crown Temperature"

3. NERVA Material Handbook

4. Detail Specification Part 1 - Performance/Design and Qualification Requirements for Nozzle Assembly, Spec. No. EC-90196B

II. INTRODUCTION

This report contains the compressive strains developed in the nozzle U-tubes as a result of jacket restraint when operating under two possible steady state thermal conditions at two axial locations along the length of the tube. The temperature conditions incorporated into this analysis were calculated by consideration of a $\pm$ 68°R tolerance factor on the normal end of life and normal throttling end of life conditions, which produced a maximum chamber temperature of 4318°R (nominal, 4250°R). For the growth operation condition the maximum chamber temperature condition of 4568°R results from the same expected tolerance of $\pm$ 68°R for the nominal 4500°R. Since the time of this analysis new 'E' engine NETAP conditions have been made available which used a more refined tolerance of $\pm$ 45°R. However, the magnitude of this change of maximum chamber temperature does not warrant re-analysis at this time. In addition the developed temperatures in the barrel section were adjusted to cause a 300 degree increase over the developed temperature to reflect an uncertainty condition.

The tube temperature profiles were calculated and the strain analysis was performed for both the max flux area (near the throat) and in the core support section (barrel section). The nozzle U-tube fabrication technique now allows that the tube thickness is variable along the length of the tube. The design thickness used in this study was $t = 0.013$ in. for the max flux area and $t = 0.023$ in. for the core support section.

According to the specifications (4)* the endurance of the nozzle tubes operating under a steady state condition is 600 min. at rated temperature accumulated in up to 60 cycles of varying duration up to 60 min. maximum per cycle. The margin (failure being a crack through condition) with respect to this operating condition will not be established in this report. However, the data presented in this report will be used in establishing the margin of safety values as soon as the fatigue properties are obtained for the material.

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*Numbers in parenthesis refer to References

Before a final assessment can be made with regards to the reliability aspect of the design, consideration should be made of the possible transient conditions which have not been investigated. The specification (4) defines operational cycles as:

(a) Sixty (60) cycles at or above engine throttle point conditions. Maximum duration per cycle not to exceed 1 hour. Up to 3 cycles of the 60 may be single TPA operations cycles, maximum duration per cycle not to exceed 1 hour.

(b) Forty-eight (48) idle mode cycles.

(c) Sixty (60) cooldown cycles. Maximum duration per cycle not to exceed 215 hours.

The terminology used by the specification to define these different conditions are:

Engine Conditioning

Temperature Conditioning

Nuclear Startup

Bootstrap

Thrust Buildup

Steady State Operation

Shutdown & Cooldown

Throttling

Throttle Hold

Cooldown - Intermittent (Pulse) Propellant Flow

Post Operations

Idle Mode Operations

Malfunction Mode Impulse

Coast Operations

This report is not neglecting the above possible operating conditions; but due to the lack of design data making the assumption that the steady state operating conditions is the most damaging and the other possible operating modes contribute little to the failure of the tubes.

III. SUMMARY & CONCLUSIONS

Two temperature gradients are incorporated into the analysis in developing the magnitude of strain at both the max flux location and in the core support section. The temperature gradients are illustrated in Figure A.

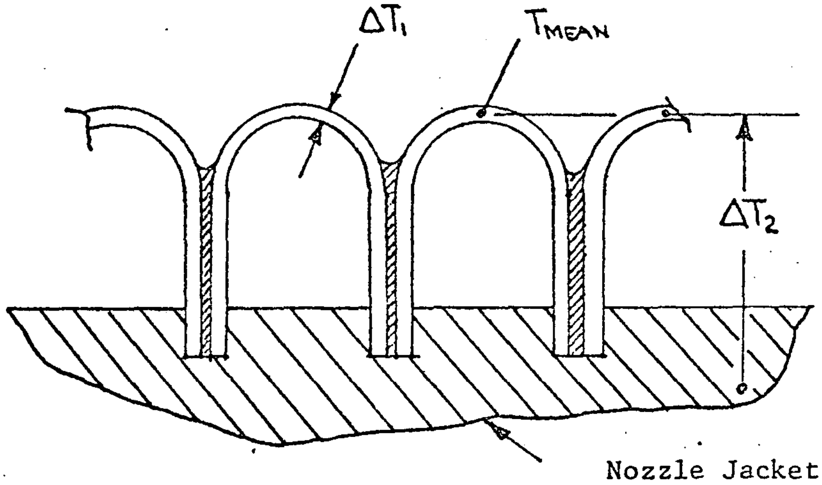

Figure A. Thermal Gradients Considered in the Strain Analysis

The magnitude of these gradients are listed below:

	ΔT_1 Thru Tube Wall	
Chamber Temp.	Maximum Flux Area	Core Support Area
$T_c = 4250^oR$	818	395
$T_c = 4500^oR$	840	420

The delta temperature between the mean wall temperature of the U-tubes and the mean wall temperature of the nozzle jacket is (using $T_{mean} \approx -300^oF$ for the nozzle jacket):

Chamber Temp.	ΔT_2 Between T_{mean} of the Tube to T_{mean} of Nozzle Jacket — Maximum Flux Area	Core Support Area
$T_c = 4250^oR$	1376	1475
$T_c = 4500^oR$	1481	1571

As was mentioned, both temperature deltas were incorporated into the analysis in developing the magnitude of strain at the two axial locations. The temperature distribution thru the tube wall at the crown location for both the max flux area and the core support section are illustrated in Figure B. The distribution is linear in both cases.

The summary of the results is listed in Table I and taken from Figure 3, page 19; Figure 4, page 24; Figure 5, page 29; and Figure 6, page 33. The referenced figures illustrate the distribution of strain (and the maximum strain location) around the circumference of the tube crown. The pressure strains were not included into this analysis because of the relatively small effect on the thermal strains.

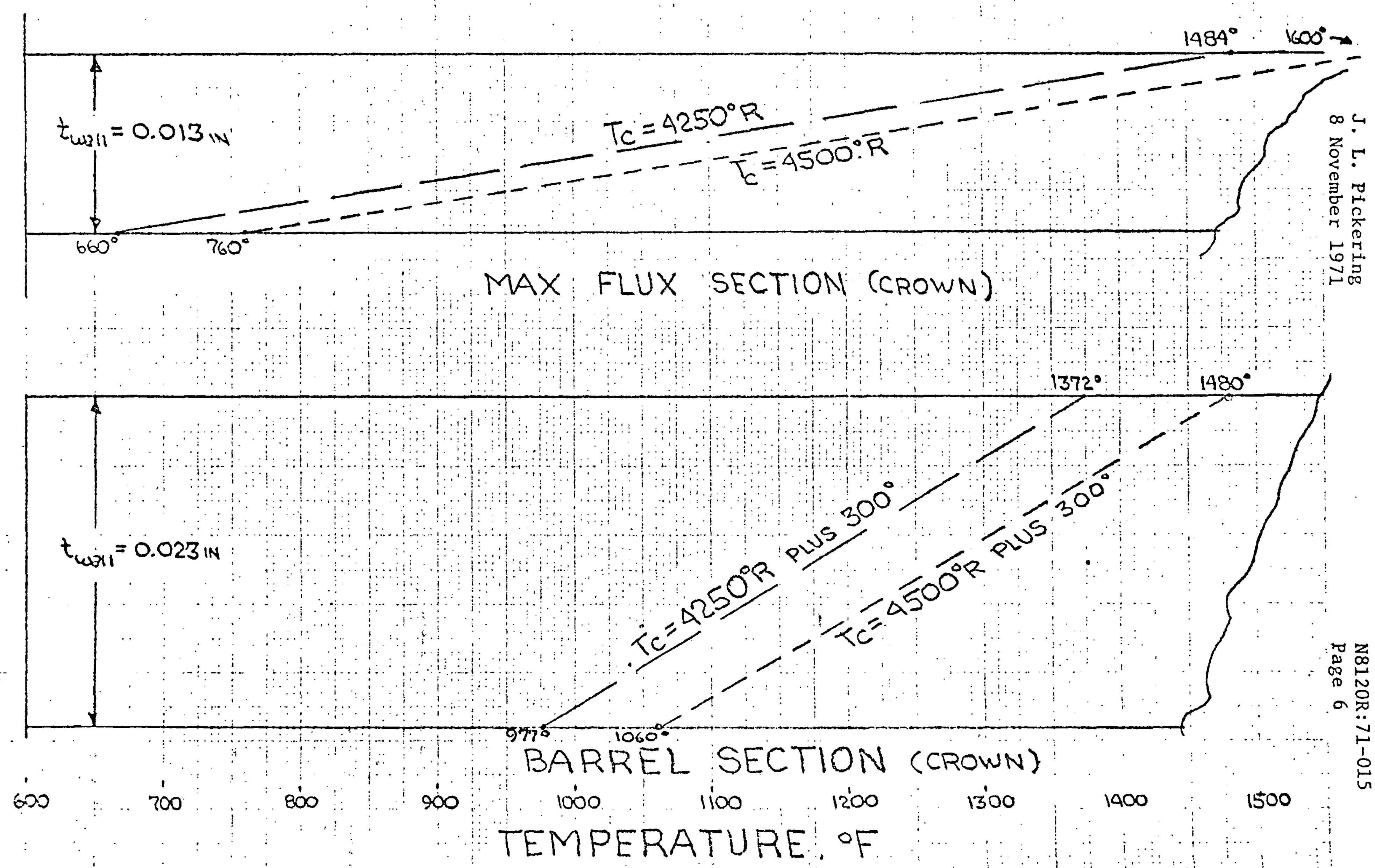

FIG. B FOUR TEMPERATURE CONDITIONS

TABLE I

SUMMARY OF RESULTS EFFECTIVE STRAIN

1. $4250^{o}R$ — MAX FLUX LOCATION

POSITION	MID-CROWN (0^{o}) ϵ	MID-CROWN (0^{o}) T(^{o}F)	MAX STRAIN (55^{o}) ϵ	MAX STRAIN (55^{o}) T(^{o}F)
$R_{outside}$	-.0196	1484	-.021	940
R_{mean}	-.0150	1075	-.0114	630
R_{inner}	-.011	666	-.0105	315

2. $4500^{o}R$ — MAX FLUX LOCATION

POSITION	MID-CROWN (0^{o}) ϵ	MID-CROWN (0^{o}) T(^{o}F)	MAX STRAIN (55^{o}) ϵ	MAX STRAIN (55^{o}) T(^{o}F)
$R_{outside}$	-.021	1600	-.0245	1150
R_{mean}	-.0164	1180	-.0145	810
R_{inner}	-.012	760	-.0126	470

3. $4250^{o}R$ PLUS 300^{o} — BARREL SECTION

POSITION	MID-CROWN (0^{o}) ϵ	MID-CROWN (0^{o}) T(^{o}F)	STRAIN (50^{o}) ϵ	STRAIN (50^{o}) T(^{o}F)
$R_{outside}$	-.0153	1370	-.0133	1100
R_{mean}	-.0143	1175	-.0097	940
R_{inner}	-.0132	977	-.0097	780

4. $4500^{o}R$ PLUS 300^{o} — BARREL SECTION

POSITION	MID-CROWN (0^{o}) ϵ	MID-CROWN (0^{o}) T(^{o}F)	STRAIN (50^{o}) ϵ	STRAIN (50^{o}) T(^{o}F)
$R_{outside}$	-.017	1480	-.0140	1200
R_{mean}	-.0146	1271	-.0105	1025
R_{inner}	-0.123	1061	-.0105	850

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IV. TECHNICAL DISCUSSION

NONLINEAR ANALYSIS WITH PROGRAM E11401

THIS PROGRAM INCORPORATES E. L. WILSON'S "A DIGITAL COMPUTER PROGRAM FOR THE FINITE ELEMENT ANALYSIS OF SOLIDS WITH NONLINEAR MATERIAL PROPERTIES", WITH MODIFICATIONS MADE BY AEROJET PERSONEL ON THE NONLINEAR SECTION OF THE ANALYSIS. A BRIEF DISCRIPTION OF THE PROGRAM WOULD BE THAT THE NONLINEAR ANALYSIS BEGINS WITH AN ELASTIC SOLUTION OF THE BODY. THIS SOLUTION RESULTS IN A SET OF ELASTIC STRESSES ACTING WITHIN EACH ELEMENT. THESE STRESSES, WHEN COMBINED IN

$$\sigma_e = \frac{1}{\sqrt{2}} \sqrt{(\sigma_r - \sigma_z)^2 + (\sigma_r - \sigma_\theta)^2 + (\sigma_z - \sigma_\theta)^2 + 6\,\sigma_{rz}^2},$$

RESULT IN AN EFFECTIVE STRESS FOR THE ELEMENT. IF THE EFFECTIVE STRESS EXCEEDS THE YIELD STRESS, THEN THE ELEMENT HAS YIELDED (V. MISES YIELD CONDITION AND ITS MATERIAL PROPERTIES MUST BE REDEFINED BEFORE PROCEEDING WITH THE NEXT SOLUTION. IN THOSE ELEMENTS WHERE $\sigma_e \leq \sigma_y$, THE INITIAL PROPERTIES OF THE MATERIAL ARE RETAINED FOR USE IN THE NEXT APPROXIMATION. ONCE AN ELEMENT HAS YIELDED, ITS PLASTIC BEHAVIOR IS GOVERNED BY A FLOW LAW BASED ON AN EFFECTIVE STRESS-STRAIN RELATION.

IF THE EFFECTIVE STRESS EXCEEDS THE YIELD STRESS, THEN THE TOTAL STRAIN WILL INCLUDE PLASTIC PORTIONS, AND THE GOVERNING STRESS STRAIN RELATION BECOME

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$$\left.\begin{aligned} \epsilon_r &= \frac{1}{E}\left\{\sigma_r - \nu(\sigma_z + \sigma_\theta)\right] \\ \epsilon_{rz} &= \frac{2(1-\nu)}{E}\,\sigma_{rz} \end{aligned}\right\} \quad (1)$$

WHERE:

$$\frac{1}{E} = \left[\frac{1}{E'} + \frac{1}{E''}\right] \text{ - - - - - - - - - } (2)$$

$$\nu = \left[\frac{\nu'\left(\frac{1}{E'}\right) + \nu''\left(\frac{1}{E''}\right)}{\left(\frac{1}{E'}\right) + \left(\frac{1}{E''}\right)}\right] \text{ - - - - - - - - } (3)$$

E', ν'; ν'' ARE MATERIAL CONSTANTS, E'' AND E AND VARIABLE FUNCTIONS, AND ν IS A VARIABLE POISSON'S RATIO.

THE FUNCTIONS E AND ν USED IN THE RESULTANT STRESS-STRAIN RELATIONS ABOVE, CAN BE COMPUTED FROM A TENSILE TEST CURVE. FIGURE 1 IS A BILINEAR REPRESENTATION OF STRESS-STRAIN DATA TAKEN FROM A STRAIN HARDENING MATERIAL. THIS CURVE IS DEFINED BY THE ELASTIC MODULUS E'. THE MODULUS n, AND THE YIELD STRESS σ_y.

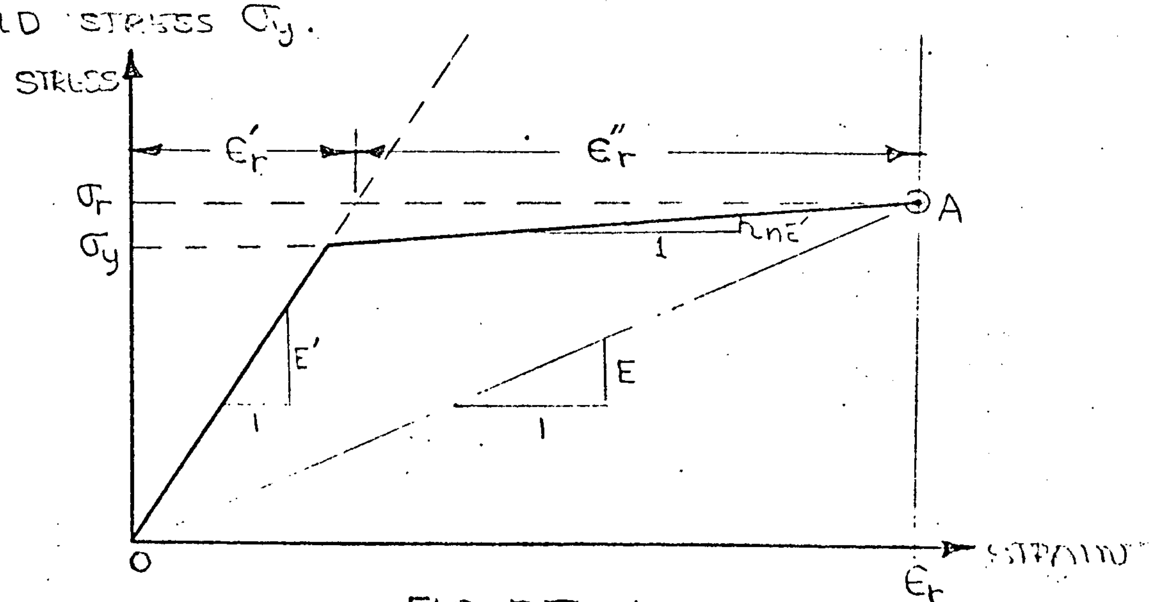

FIGURE 1

THE PARAMETERS E AND ν MUST BE DETERMINED BY ITERATION BECAUSE THE POINT A ON THE STRESS-STRAIN CURVE (FIGURE 1) IS NOT KNOWN (FOR A BILINEAR MATERIAL ONLY E IS A VARIABLE). THE ITERATION IS ACCOMPLISHED BY INITIALLY SOLVING THE ELASTIC PROBLEM. FIGURE 1 IS REDRAWN AS FIGURE 2 BY REPLACING THE TENSILE STRESS, STRAIN AXES WITH EFFECTIVE STRESS AND STRAIN.

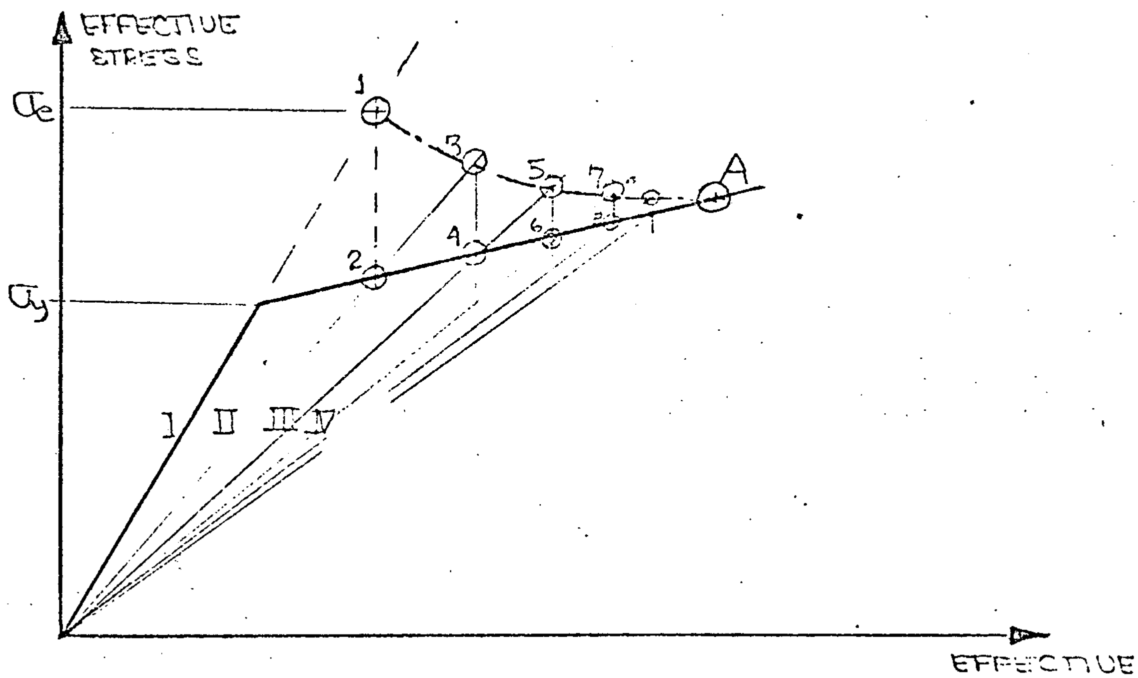

FIGURE 2

POINT 1 REPRESENTS THE EFFECTIVE STRESS IN A PARTICULAR ELEMENT, AND ASSUMING ELASTIC BEHAVIOR (E_I). THIS ELEMENT HAS YIELDED, AND ITS EQUILIBRIUM LOCATION WILL BE AT SOME UNKNOWN POINT A. THE LOCATION OF A IS APPROXIMATED BY ASSUMING THE STRAIN OF POINT 1 BUT THE EFFECTIVE STRESS CORRESPONDING TO POINT 2 ON THE STRESS-STRAIN

CURVE. E_{II} AND ν_{II} ARE FOUND USING EQUATIONS (2), (3) AND

$$\frac{1}{E} = \frac{1}{nE'}\left[1 - \frac{\sigma_y}{\sigma_r}(1-n)\right] \text{------} \quad (4)$$

SIMILAR VALUES ARE ESTABLISHED FOR EACH YIELDED ELEMENT, AND THE PROBLEM IS RESOLVED WITH THE CORRECTED MATERIAL PROPERTIES. BASED ON THE SECOND ITERATION, THE EFFECTIVE STRESS CORRESPONDS TO POINT 3. THE NEXT ESTIMATE FOR POINT A IS ASSUMED TO BE AT 4, AND THE PROCEDURE IS REPEATED. THE SOLUTION HAS CONVERGED WHEN POINTS A IN EACH ELEMENT DO NOT MOVE SIGNIFICANTLY WITH SUCCESSIVE ITERATIONS.

THE PROBLEM CONSIDED IN THIS JOB IS MAINLY A THERMO-PLASTIC ANALYSIS. THE PROCEDURE FOR CALCULATING ELASTIC THERMAL STRESSES IS TO TREAT THERMAL LOADS AS ANALOGOUS BODY FORCES. NODAL FORCES REQUIRED TO RESTRAIN THE NODES WHEN THE ELEMENT IS SUBJECT TO A TEMPERATURE CHANGE ΔT ARE CALCULATED AND SUPERIMPOSED UPON POSSIBLE MECHANICAL LOADS DUE TO PRESSURE. THE EQUILIBRIUM EQUATIONS ARE SOLVED FOR THE NODAL DISPLACEMENTS WHICH ARE CONVERTED TO MECHANICAL STRAINS ACTING WITHIN THE ELEMENT. WITH KNOWN STRAINS, THE STRESSES ARE CALCULATED USING

$$\{\sigma\} = [C]\{\epsilon\} - \{\tau\} \text{-----} \; 5$$

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THE VECTOR $\{\tau\}$ CONTAINS THE RESTRAINED THERMAL STRESSES ($E\alpha\Delta T$ TERMS).

THUS, THE NET OR RESULTANT THERMAL STRESSES ARE FOUND BY SUPERIMPOSING THE RESTRAINED THERMAL STRESSES $\{\tau\}$ WITH THE STRESSES CALCULATED UNDER THE ACTION OF THE ANALOGOUS BODY FORCES. THE ELASTIC SOLUTION WILL RESULT IN THE HIGHEST VALUE OF THERMAL STRESS BECAUSE THE MAGNITUDE OF THERMAL STRESS IS PROPORTIONAL TO THE MODULUS OF THE MATERIAL AND E IS A MAXIMUM WHEN THE ELEMENT IS PURELY ELASTIC. THE EXTENT OF YIELDING IS ESTABLISHED FROM THE FIRST ITERATION. SUCCESSIVE ITERATION CAUSES THERMAL STRESSES TO RELAX UNTIL EVERY ELEMENT IS IN EQUILIBRIUM, BUT THE YIELD ZONE DOES NOT EXPAND AS MIGHT BE POSSIBLE FOR THE CASE OF APPLIED MECHANICAL LOADS.

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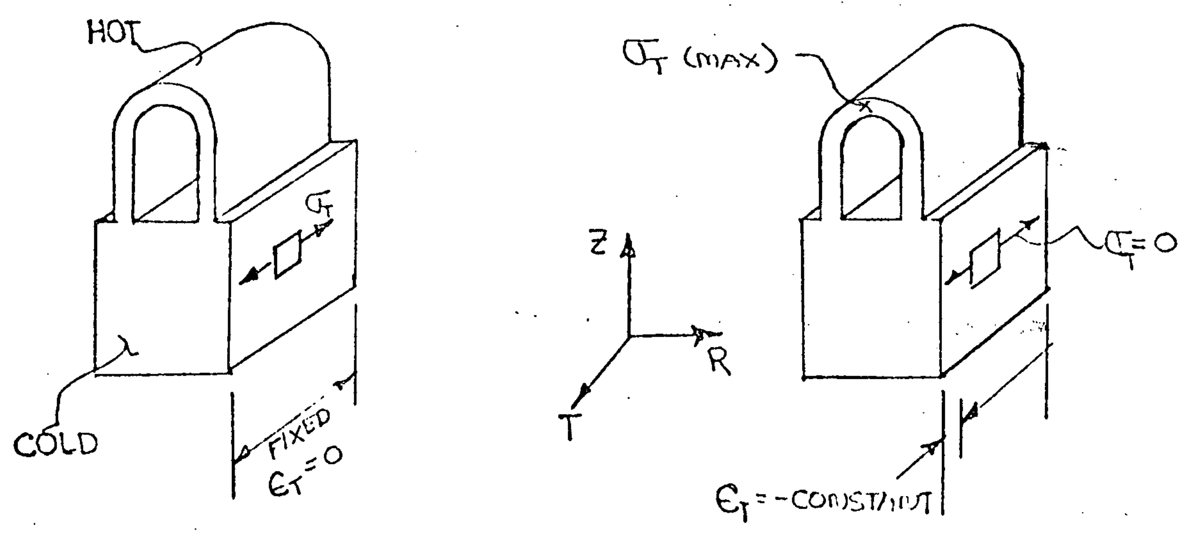
THE GENERALIZED PLANE STRAIN OPTION IS USED IN THIS ANALYSIS. WITHOUT THIS OPTION THE OUT OF PLANE STRAIN WOULD BE SET EQUAL TO ZERO ($\epsilon_T = 0$, AS IS STIPULATED IN THE PLANE STRAIN CASE). THIS CONDITION WOULD NOT SIMULATE THE ACTUAL PROBLEM, IN THAT THE NOZZLE JACKET IS ACTUALLY FREE TO CONTRACT (CRYOGENIC TEMPERATURES). THE MOVEMENT OF THE NOZZLE JACKET WILL INTRODUCE ADDITIONAL STRAINS (COMPRESSIVE) IN THE TUBES WHICH CAN BE INCLUDED USING THE GENERALIZED PLANE STRAIN OPTION BY INTRODUCING A FREE GROWTH OUT OF PLANE STRAIN (ϵ_T = CONSTANT) ON THE MODEL. THIS STRAIN IS APPLIED TO ALL OF THE ELEMENTS OF THE MODEL, THEREFORE IS JUST AN AVERAGE VALUE. THE VALUE USED IN THESE MODELS WAS CHOSEN TO REDUCE THE LOAD DEVELOPED (OUT OF PLANE LOAD) IN THE JACKET PORTION TO A ZERO LOADING CONDITION (A ZERO LOADING CONDITION WAS NOT OBTAINED IN EITHER CASE BUT WAS CLOSE ENOUGH TO SIMULATE THE ACTUAL PROBLEM).



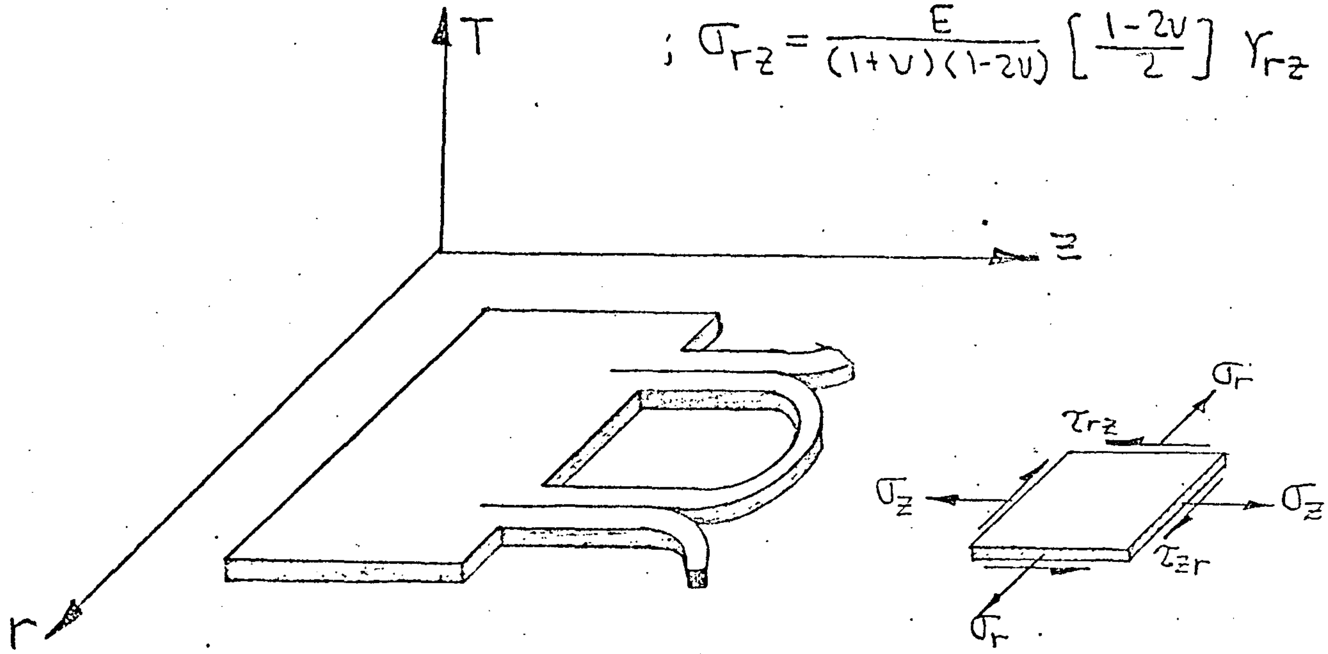
GENERALIZED PLANE STRAIN

$$\epsilon_r = \frac{1}{E}\left[\sigma_r - \nu(\sigma_z + \sigma_T)\right] \quad ; \quad \sigma_r = \frac{E}{(1+\nu)(1-2\nu)}\left[\epsilon_r(1-\nu) + \nu\epsilon_z\right]$$

$$\epsilon_z = \frac{1}{E}\left[\sigma_z - \nu(\sigma_r + \sigma_T)\right] \quad ; \quad \sigma_z = \frac{E}{(1+\nu)(1-2\nu)}\left[\epsilon_z(1-\nu) + \nu\epsilon_r\right]$$

$$\epsilon_T = 0 = \bar{\epsilon} \quad ; \quad \sigma_T = \nu(\sigma_r + \sigma_z)$$

$$; \quad \sigma_{rz} = \frac{E}{(1+\nu)(1-2\nu)}\left[\frac{1-2\nu}{2}\right]\gamma_{rz}$$



$$\{\sigma\} = [D]\{\epsilon\}$$

WHERE:

$$[D] = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix} (1-\nu) & \nu & 0 \\ \nu & (1-\nu) & 0 \\ 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix}$$

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DETERMINING THE POISSON'S RATIO USED IN THE FINAL ITERATION BY THE FOLLOWING FORMULA.

$$\nu_{i+1} = \frac{E_{i+1}}{\bar{E}}\bar{\nu} + \frac{1}{2}\left(1 - \frac{E_{i+1}}{\bar{E}}\right)$$

$\bar{E}$ = INITIAL ELASTIC MODULUS

$\bar{\nu}$ = INITIAL ELASTIC POISSON'S RATIO

ELEMENT 98 -- (4500°R) MAX FLUX LOCATION

$i=0 \qquad \nu_1 = \frac{19.725E6}{19.725E6}(.340) + \frac{1}{2}(1-1) = 0.34$

$i=1 \qquad \nu_2 = (.5196)(.34) + \frac{1}{2}\left(1 - \frac{10.249}{19.725}\right)$
$\qquad = 0.1767 + .2402 = 0.4169$

$i=2 \qquad \nu_3 = (.2792)(.4169) + \frac{1}{2}(1-.2792)$
$\qquad = 0.1164 + .3604 = 0.4768$

$i=3 \qquad \nu_4 = .0387(.4768) + \frac{1}{2}(1-.0387)$
$\qquad = .01845 + .4806 = 0.4991$

$i=4 \qquad \nu_5 = .03855(.4991) + \frac{1}{2}(1-.03855)$
$\qquad = .01927 + .4807 = 0.49997$

$i=5 \qquad \nu_6 = (.03855)(.49997) + \frac{1}{2}(1-.03855)$
$\qquad = .019299 + .4807 = 0.50$

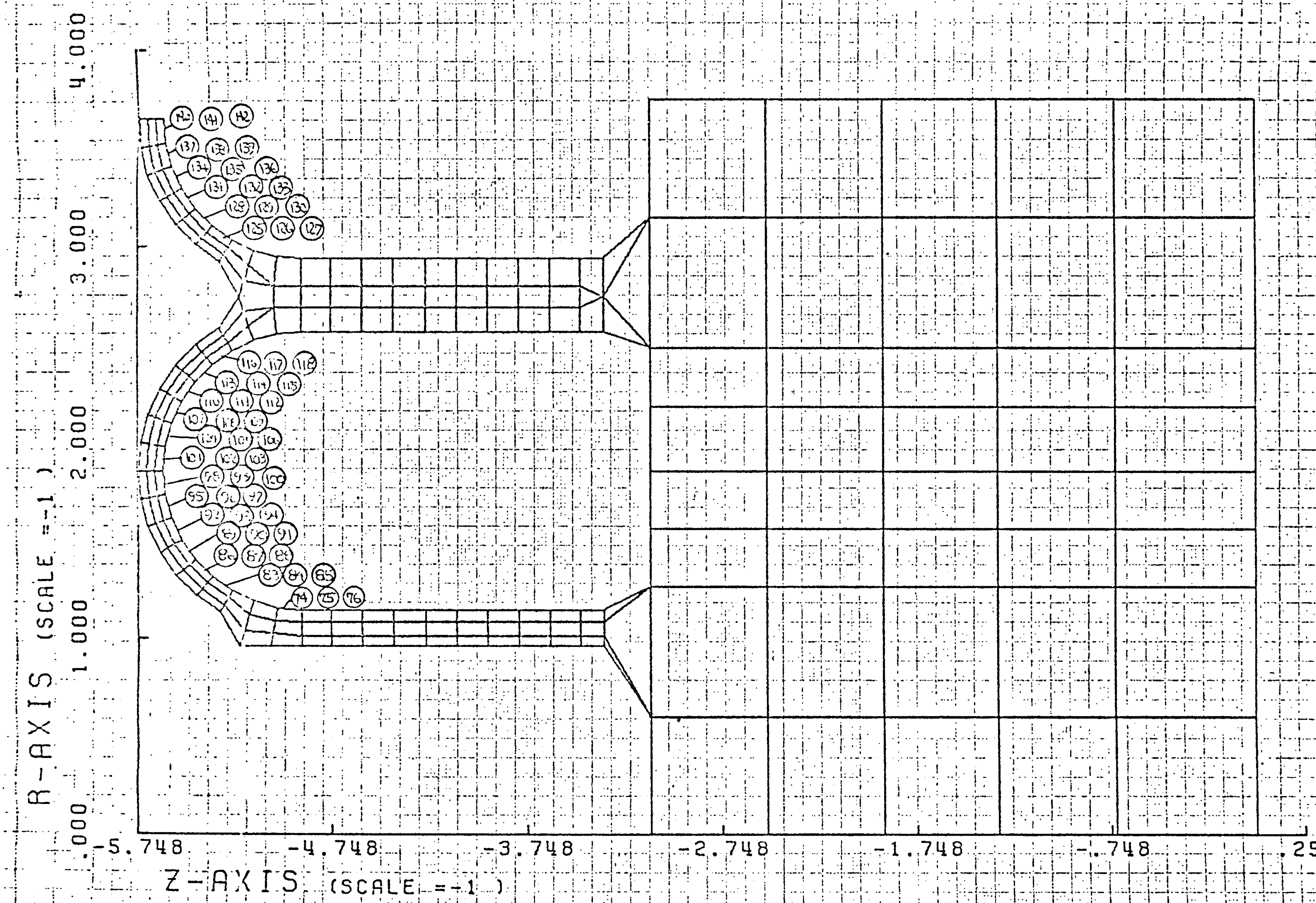
$i=6 \qquad \nu_7 = 0.02978(.5) + \frac{1}{2}(1-.02978)$
$\qquad = .01489 + .4851 = 0.49999$

$i=7 \qquad \nu_8 = .02973(.49999) + \frac{1}{2}(1-.02973)$
$\qquad = .014865 + .4851 = 0.49997$

$i=8 \qquad \nu_9 = .02973(.49997) + \frac{1}{2}(1-.02973)$
$\qquad = .014864 + .4851 = 0.49996$

$\nu \approx 0.50$

V. FINITE ELEMENT MODEL AND TABULARIZED RESULTS



NOZZLE TUBES (MAX FLUX LOC)
3/31/71 PLANE STRESS (4500)

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4250°R (4318°R) MAX FLUX LOCATION

RESULTS: ELEMENT STRAINS

ELEMENT No.	TEMP °F	σ_T	$\frac{E_S}{E_i}$	$E_i \times 10^6$	$\epsilon_T = \frac{\sigma_T}{E_S}$	LOCATION FROM MID-CROWN (DEGREES)	ϵ_{EFF} *
98	1342	-14072	.037	20.5	-.0186	5°	.0182
99	1068	-20031	.0549	22.4	-.0163		.0151
100	995	-25594	.0762	22.8	-.0147		.0122
95	1323	-15100	.038	20.6	-.0193	15°	.0181
96	1051	-20544	.0557	22.5	-.0169		.0150
97	781	-24952	.0781	24.3	-.0131		.0119
92	1258	-17229	.041	21.0	-.020	25°	.018
93	990	-21693	.059	22.8	-.016		.0145
94	724	-23193	.083	24.6	-.011		.0113
89	1161	-20094	.0443	21.6	-.021	35°	.018
90	903	-22691	.0647	23.5	-.0149		.014
91	644	-20180	.0882	25.2	-.009		.011
86	1023	-22422	.0472	22.6	-.021	45°	.0183
87	790	-25493	.0732	24.2	-.0149		.0128
88	557	-14485	.0877	25.8	-.0064		.0111
83	836	-28374	.0528	24.0	-.0228	55°	.0177
84	628	-24967	.0594	25.4	-.0111		.011
85	419	-7592	.0921	26.8	-.003		.0106
125	831	-29946	.0528	24.0	-.0236	55°	.0177
126	615	-26212	.0903	25.4	-.0114		.0109
127	398	-6623	.0941	26.9	-.0026		.0105
80	682	-29815	.0697	25.0	-.0171	65°	.0139
81	465	-31463	.1156	26.5	-.0103		.0086
82	248	-8985	.1154	28.0	-.0028		.0088
77	403	-34233	.1237	26.9	-.0103	75°	.008
78	218	-33210	.1713	28.1	-.0069		.0061
79	33	-20652	.2103	29.5	-.0033		.0053
74	51	-36180	.2359	29.3	-.0052	85°	.0046
75	-43	-34333	.3239	30.0	-.0035		.0038
76	-156	-34506	.4434	30.7	-.0025		.003

*SEE NOTE ON pg 28.

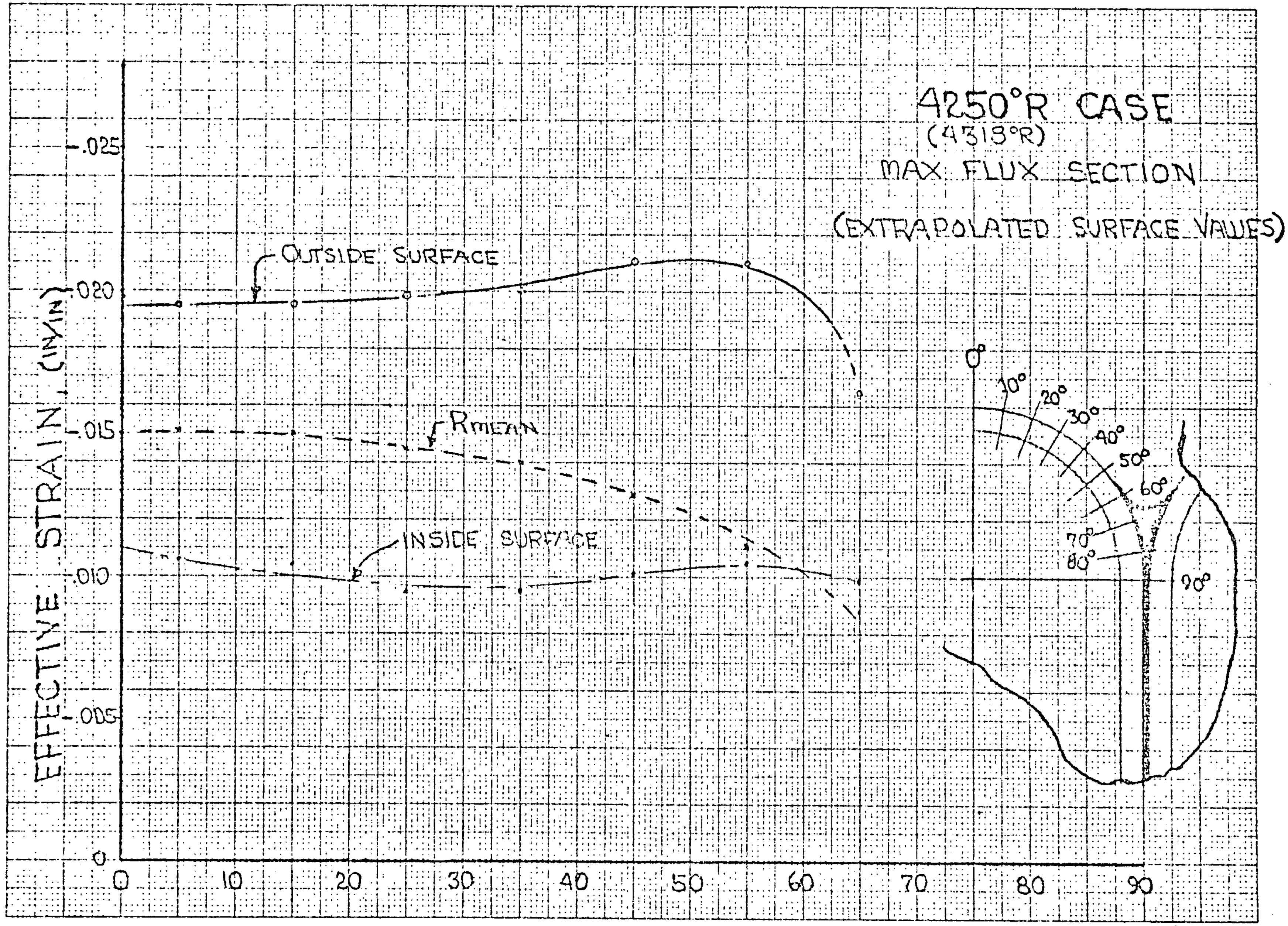


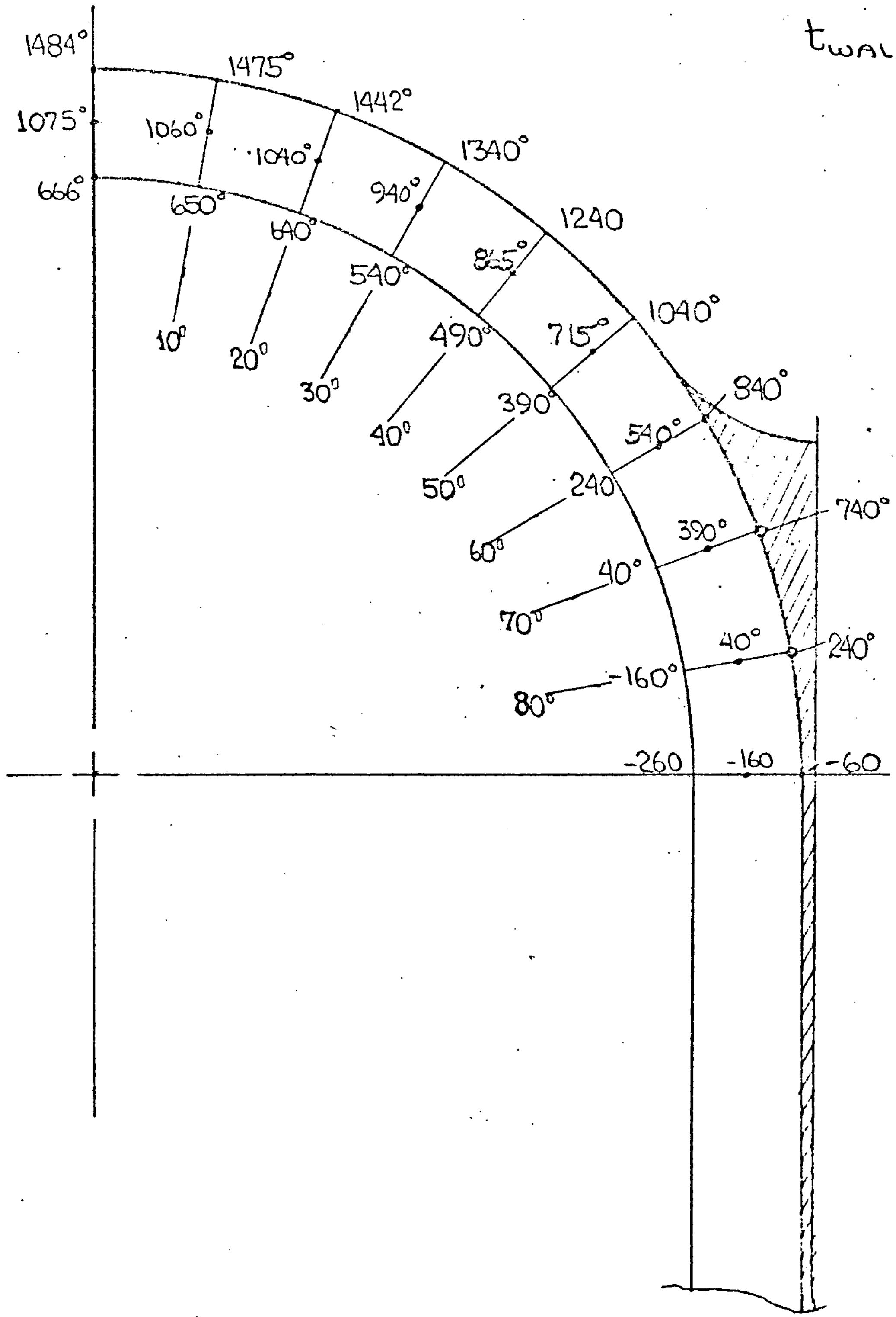
FIG 3 LOCATION FROM CROWN MIDPOINT, (DEGREES)

MAX FLUX SECTION
$T_c = 4250\,^\circ R$ ($4313^\circ R$)

MINIMUM HEATING RATES

TEMPERATURES °F
(REF 1)

$t_{WALL} = 0.013$



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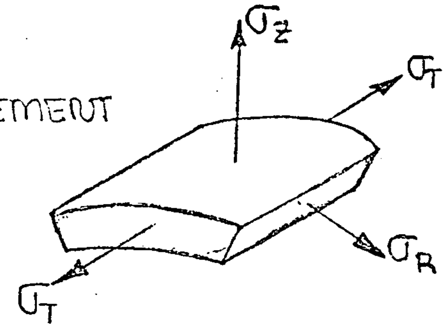
ELEMENT 98 (MID-CROWN-5°)

TOP SURFACE ELEMENT



4250°R

$T_{MEAN} = 1343°F$

STRAINS: $\epsilon_R = .0021$

$\epsilon_Z = .0024$

$\epsilon_T = -.0097$

STRESS: $\sigma_R = -1002.$

$\sigma_Z = 216.$

$\sigma_T = -14073.$

EFFECTIVE STRESS, STRAIN

$\epsilon_e = .0182$

$\sigma_e = 13718$

PRINCIPLE STRESS (r-z PLANE)

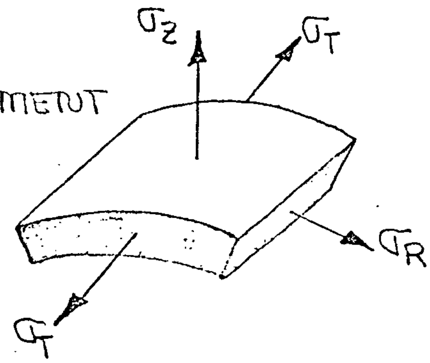
$\sigma_{MAX} = 216.$

$\sigma_{MIN} = -1002$

$\theta = 0.69$

TYPICAL STRESS-STRAIN DISTRIBUTION OF AN ELEMENT (MAX FLUX LOCATION)

ELEMENT 125 (MAX STRAIN LOCATION-55°)



4250°R
T_{MEAN} = 831 °F

STRAINS: $\epsilon_R = .0134$

$\epsilon_Z = .0136$

$\epsilon_T = -.0047$

STRESS: $\sigma_R = -14542$

$\sigma_Z = -14353.$

$\sigma_T = -29946.$

EFFECTIVE STRESS, STRAIN

$\epsilon_e = .0177$

$\sigma_e = 22549$

PRINCIPLE STRESS (r-z PLANE)

$\sigma_{max} = -4988.$

$\sigma_{min} = -23906$

$\theta = -44.7$

TYPICAL STRESS-STRAIN DISTRIBUTION OF AN ELEMENT (MAX FLUX)

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4500°R (4568°R) MAX FLUX. LOCATION

RESULTS: ELEMENT STRAINS

ELEMENT No.	TEMP. °F	σ_T	$\frac{E_S}{E_i}$	$E_i \times 10^6$	$\epsilon_T = \frac{\sigma_T}{E_S}$	LOCATION From MID-CROWN	ϵ_{EFF}*
98	1459	-11361	.0297	19.6	-.0195	5°	.0195
99	1178	-17896	.0481	21.5	-.0173		.0163
100	896	-24623	.0666	23.5	-.0157		.0134
95	1444	-12155	.0305	19.8	-.020	15°	.0195
96	1161	-18223	.0487	21.6	-.0173		.0162
97	879	-23830	.0686	23.6	-.0148		.0131
92	1418	-13659	.0311	20.0	-.022	25°	.0198
93	1137	-19004	.0495	21.8	-.0176		.0162
94	853	-22232	.071	23.7	-.0132		.0128
89	1347	-15853	.0331	20.4	-.0235	35°	.0204
90	1080	-20030	.052	22.2	-.0174		.0159
91	813	-19437	.0723	24.0	-.0112		.0127
86	1234	-18570	.036	21.2	-.0243	45°	.0213
87	992	-23060	.0567	22.4	-.0182		.0152
88	750	-13981	.0698	24.4	-.0082		.0134
83	1037	-25836	.0417	22.5	-.0275	55°	.0207
84	810	-23748	.0704	22.4	-.0141		.0132
85	583	-7624	.0762	25.6	-.0039		.0127
125	1037	-26814	.0414	22.5	-.0288	55°	.0208
126	810	-24147	.0706	24.0	-.0143		.0132
127	583	-7172	.0766	25.6	-.0037		.0126
80	848	-28372	.0568	23.9	-.0209	65°	.0162
81	605	-29471	.0971	25.5	-.0119		.010
82	361	-8308	.0973	27.1	-.0032		.010
77	498	-32523	.1090	26.2	-.0114	75°	.0091
78	315	-32096	.1443	27.5	-.0081		.007
79	131	-19308	.1636	23.7	-.0042		.0064
74	55	-32690	.2332	29.3	-.0048	85°	.0047
75	-30	-31767	.3051	29.9	-.0035		.0039
76	-110	-36442	.3925	30.5	-.003		.0032

*SEE NOTE ON pg 28

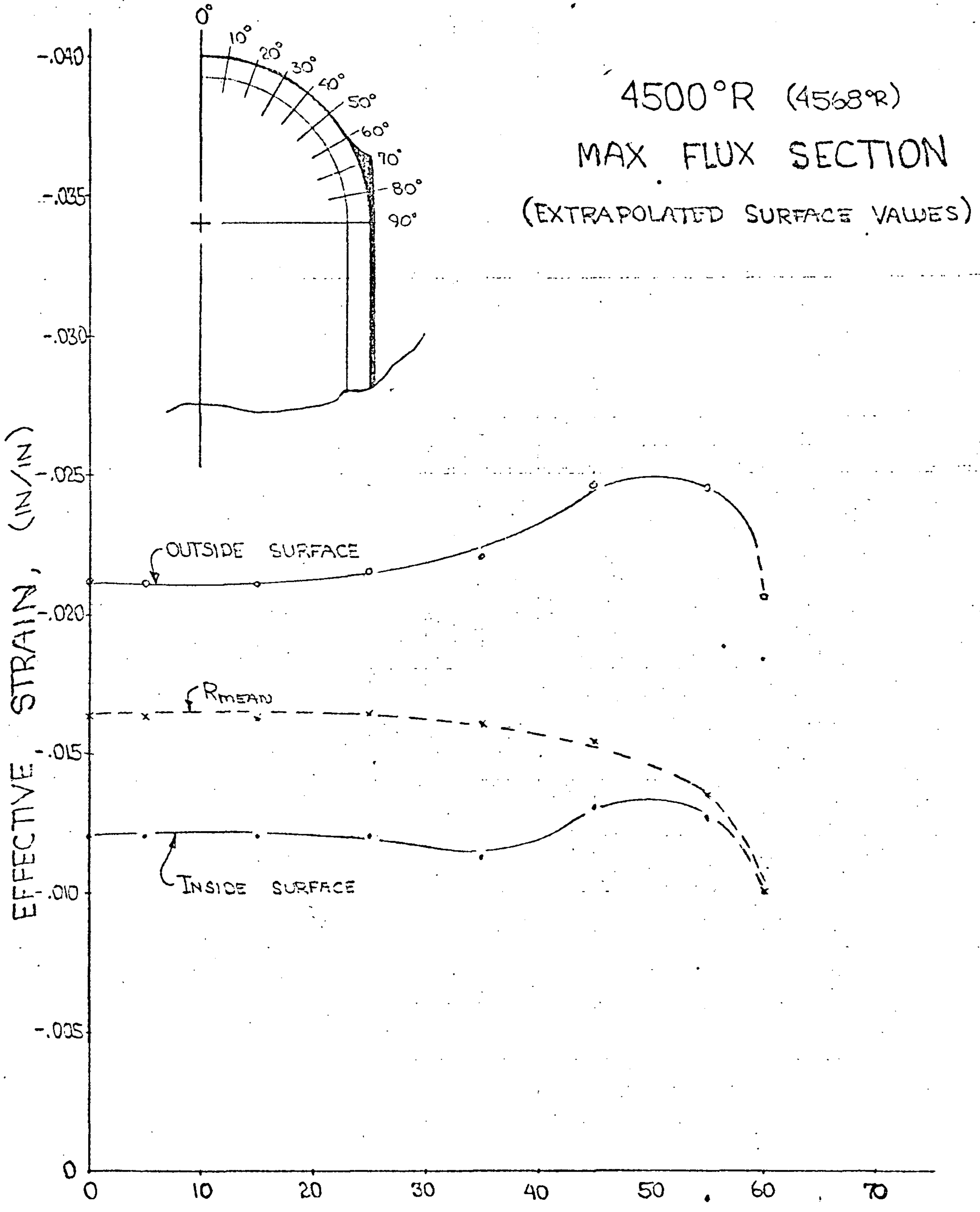
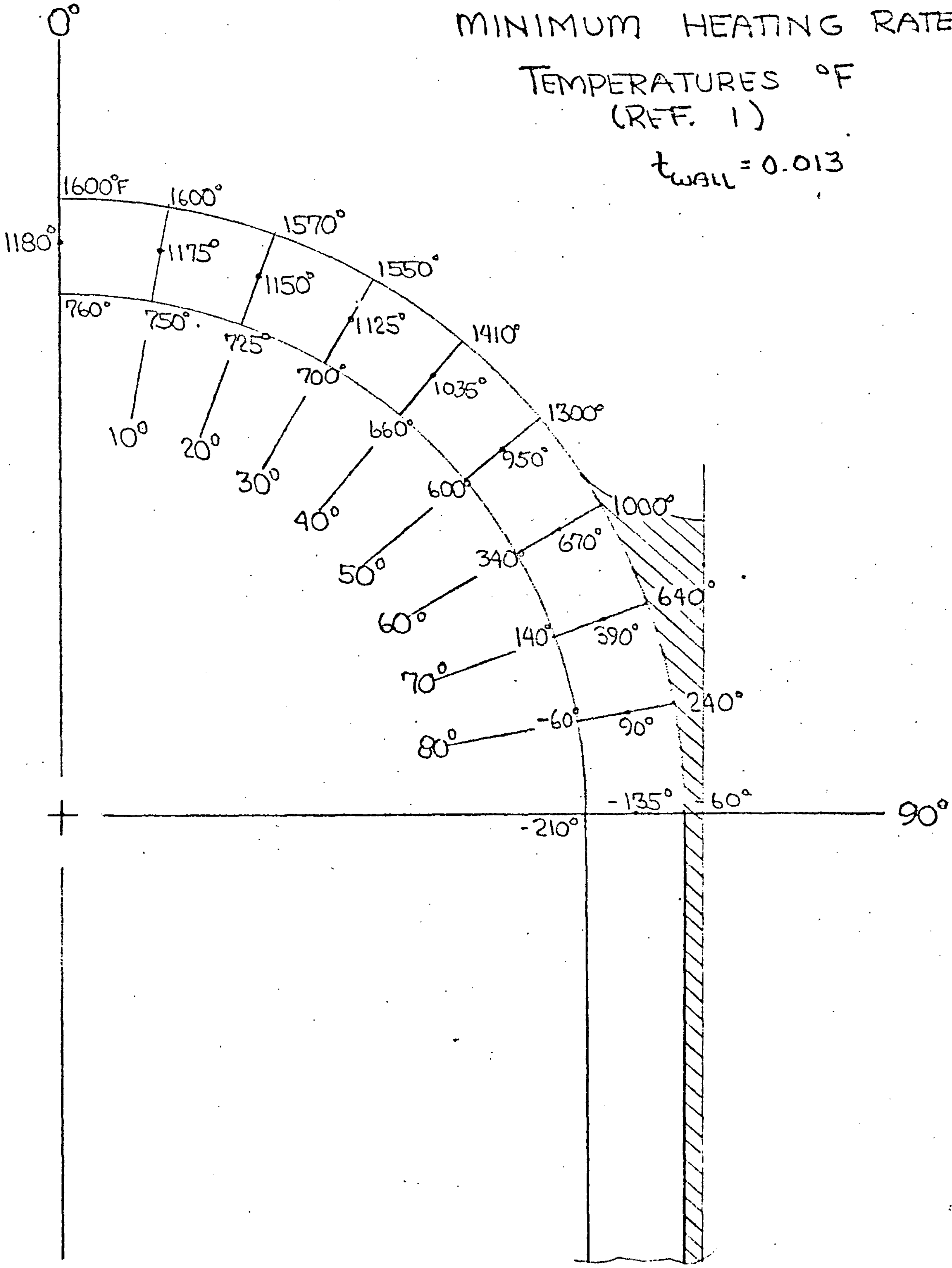
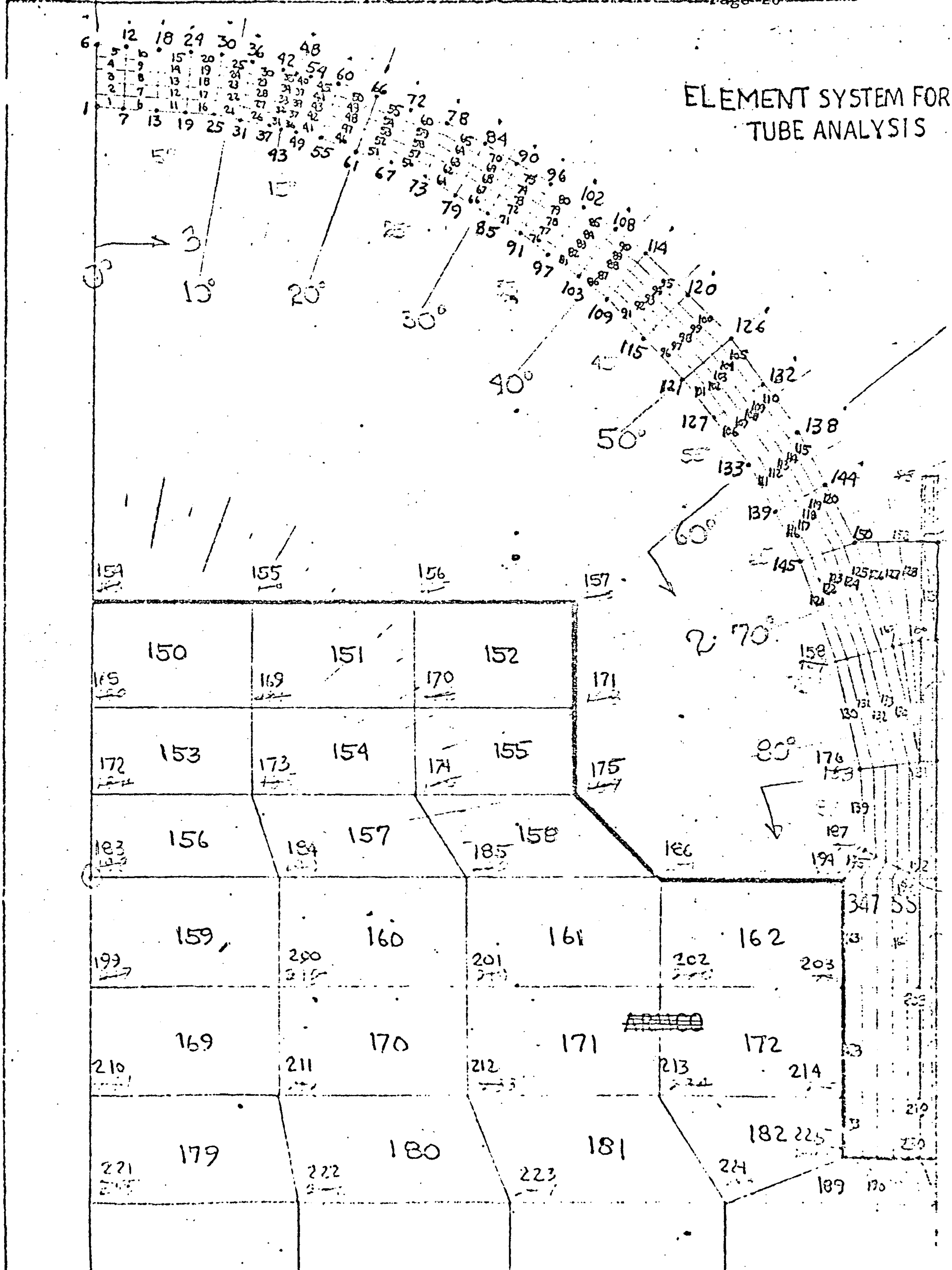


FIG 4 LOCATION FROM CROWN MIDPOINT (DEGREES)

MAX FLUX SECTION
$T_c = 4500°R$ (4568°R)
MINIMUM HEATING RATES
TEMPERATURES °F
(REF. 1)
$t_{WALL} = 0.013$




ELEMENT SYSTEM FOR
TUBE ANALYSIS

AGCS-0800-11

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

REPORT NO.	PAGE OF
SUBJECT	DATE 5/26/71
	WORK ORDER
BY JLP	CHK. BY	DATE

4250°R (4318°R) PLUS 300° BARREL SECTION

RESULTS: ELEMENT STRAINS

ELEMENT No.	TEMP °F	σ_T	$\frac{E_S}{E_i}$	$E_i \times 10^6$	$\epsilon_T = \frac{\sigma_T}{E_S}$	LOCATION FROM MID-CROWN	ϵ_{EFF}*
5	1324	-13521	.0448	20.6	-.0147		.0152
4	1250	-15030	.0511	21.1	-.0139		.0144
3	1179	-17676	.0574	21.5	-.0143	0°	.0135
2	1101	-18576	.0638	22.0	-.0134		.0127
1	1020	-20953	.071	22.7	-.0130		.0119
10	1320	-13697	.0451	20.6	-.0147		.0151
9	1248	-15796	.0514	21.1	-.0146		.0143
8	1174	-16502	.0578	21.5	-.0133	2.5°	.0135
7	1097	-19450	.0643	22.0	-.0137		.0126
6	1017	-20432	.0714	22.7	-.0126		.0118
40	1289	-14630	.0478	20.9	-.0147		.0145
39	1217	-16421	.0548	21.3	-.0142		.014
38	1144	-17627	.0603	21.7	-.0135	15°	.0132
37	1067	-19583	.0669	22.4	-.0131		.0123
36	964	-20520	.0772	23.0	-.0117		.0112
70	1189	-18357	.0556	21.5	-.0154		.0139
69	1121	-18837	.0616	22.0	-.0139		.013
68	1051	-19665	.0683	22.5	-.0128	30°	.0122
67	979	-19215	.0759	23.0	-.0111		.0114
66	905	-19126	.0823	23.0	-.0099		.0107
80	1131	-20032	.0586	21.9	-.0156		.0137
79	1069	-20036	.0655	22.4	-.0137		.0126
78	1007	-21308	.0726	22.7	-.0129	35°	.0117
77	941	-18891	.0792	23.1	-.0103		.011
76	872	-18942	.0844	23.6	-.0095		.0105
90	1078	-21972	.0621	22.2	.0159		.0133
89	1015	-20136	.0701	22.7	.0127		.0121
88	951	-24378	.0790	23.0	.0134	40°	.01099
87	883	-17977	.0855	23.5	.009		.0104
86	814	-16593	.0892	24.0	.008		.0103

SUBJECT | DATE 5/26/71 | WORK ORDER

BY JLP | CHK. BY | DATE

4250°R (4318) PLUS 300° BARREL SECTION (CONT.)

RESULTS: ELEMENT STRAINS

ELEMENT No.	TEMP °F	σ_T	$\frac{E_s}{E_i}$	$E_i \times 10^6$	$\epsilon_T = \frac{\sigma_T}{E_s}$	LOCATION FROM MID-CROWN	ϵ_{EFF} *
95	1036	-22148	.0654	22.5	.0151	45°	.0129
94	974	-23974	.0744	23.0	.014		.0116
93	911	-19317	.0828	23.4	.010		.0107
92	845	-20865	.0906	23.8	.0097		.010
91	776	-16275	.0924	24.3	.0072		.010
105	923	-23776	.0732	23.3	.0139	52°	.012
104	853	-24113	.0868	23.7	.0117		.0104
103	791	-23803	.0992	24.2	.0099		.0093
102	727	-19066	.1068	24.6	.0073		.0088
101	660	-14562	.1051	25.0	.0055		.0091
110	849	-24335	.0788	23.7	.013	55°	.0116
109	782	-29956	.0973	24.2	.0127		.0096
108	724	-20882	.1095	24.6	.0078		.0086
107	664	-24150	.1166	25.0	.0083		.00818
106	601	-10586	.1101	25.5	.0038		.0088
115	770	-27436	.0884	24.3	.0128	60°	.0106
114	717	-23756	.1026	24.6	.0094		.0092
113	650	-29129	.1245	25.2	.0093		.0077
112	593	-15282	.1272	25.5	.0047		.0076
111	533	-13725	.1166	26.0	.0045		.0083
120	683	-40307	.1071	25.0	.015	65°	.0089
119	632	-38540	.1281	25.3	.0119		.0075
118	567	-22381	.1392	25.7	.0063		.007
117	514	-20864	.1375	26.1	.0058		.0071
116	450	-4133	.1228	26.5	.0013		.008

* THE EFFECTIVE STRESS IS COMPUTED FROM THE FOLLOWING EXPRESSION

$$\sigma_{EFF} = \frac{1}{\sqrt{2}} \sqrt{(\sigma_r - \sigma_z)^2 + (\sigma_r - \sigma_T)^2 + (\sigma_z - \sigma_T)^2 + 6\tau_{rz}^2}$$

THE EFFECTIVE STRAIN IS THE EFFECTIVE STRESS DIVIDED BY THE CURRENT VALUE OF THE SECANT MODULUS.

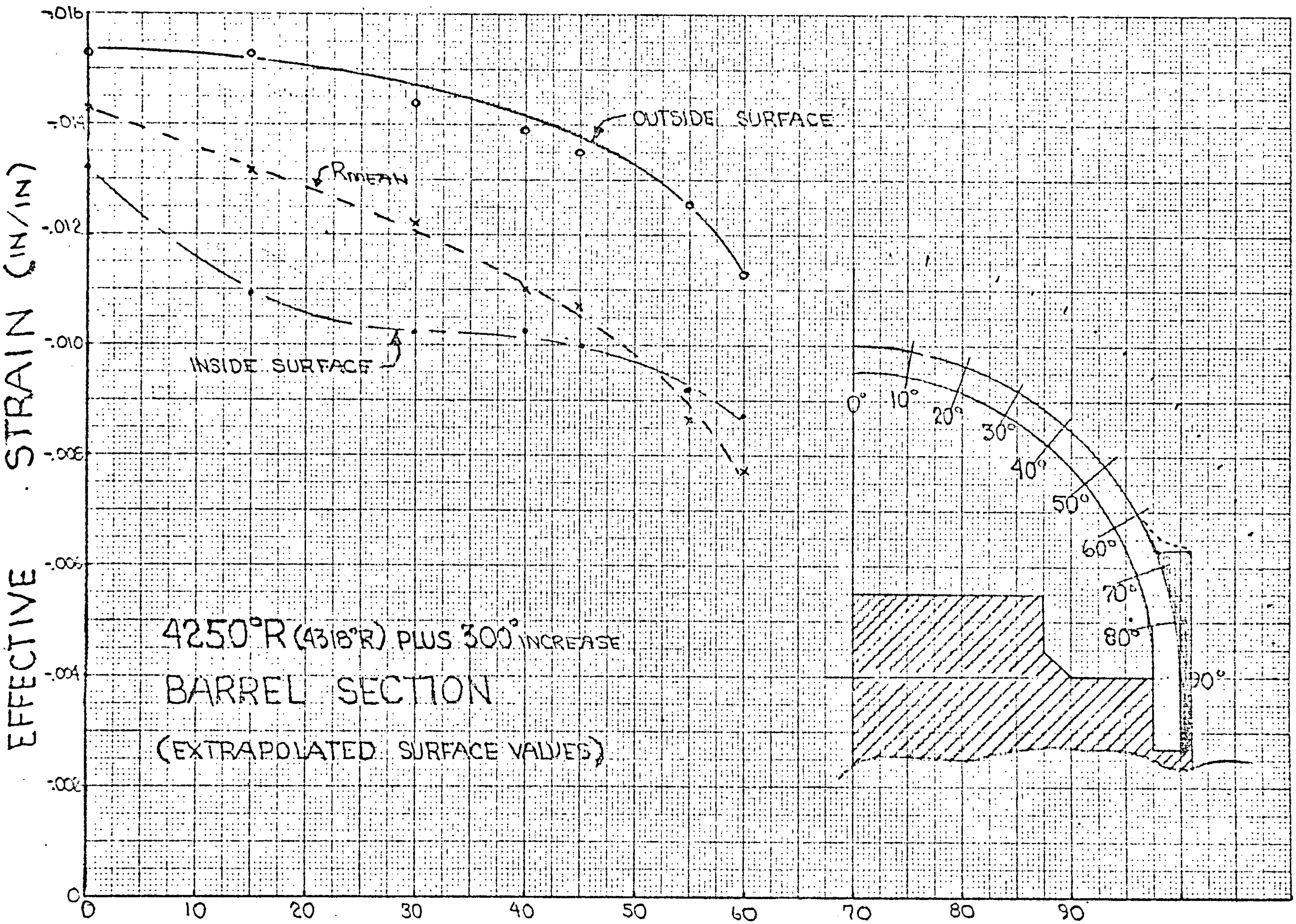
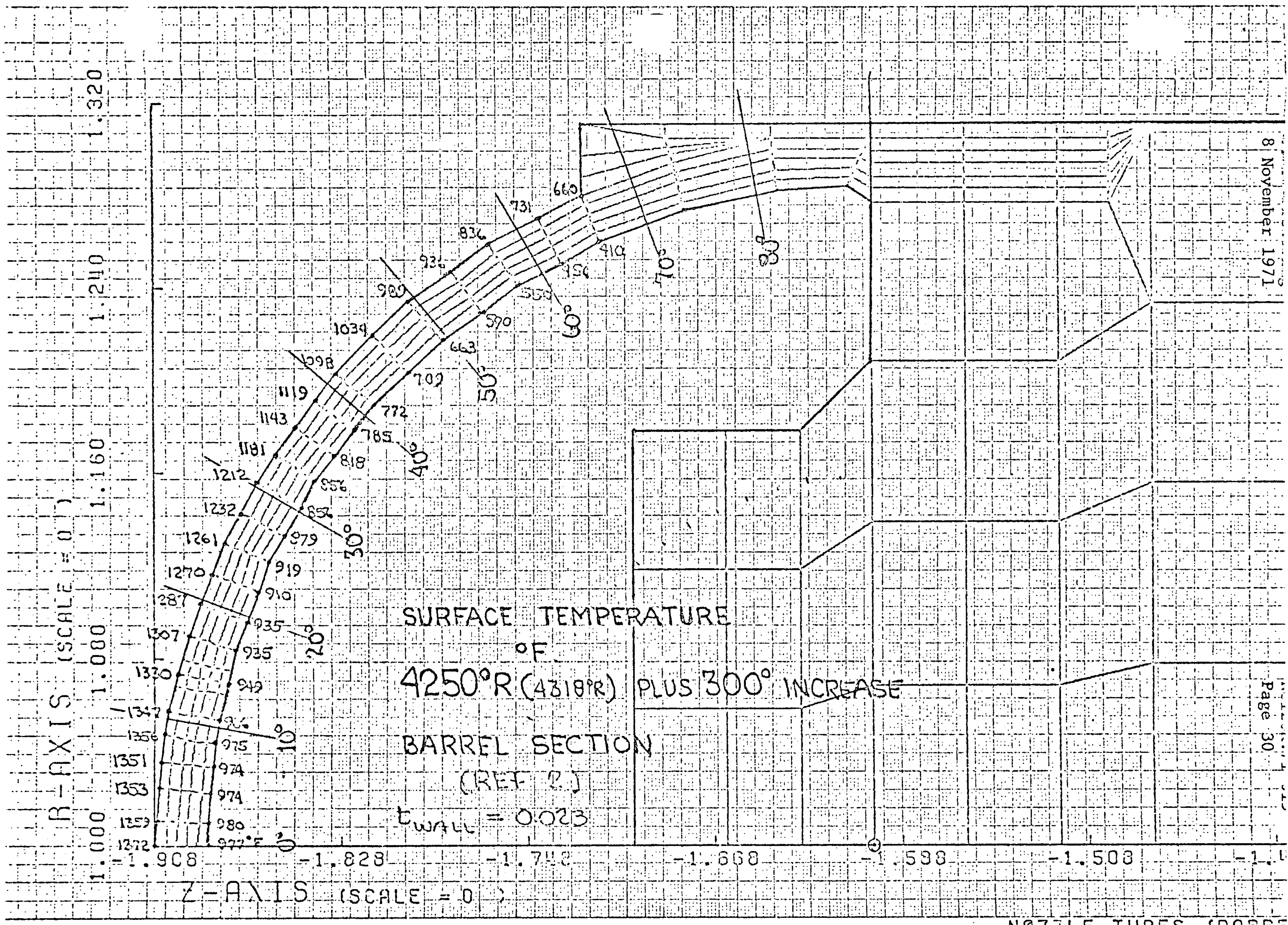


FIG 5. LOCATION FROM CROWN MIDPOINT (DEGREES)



NOZZLE TUBES (BARRE
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AERO JET GENERAL AEROJET-GENERAL CORPORATION
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AGCS-0800-11

REPORT NO.	PAGE OF
SUBJECT	DATE 5/27/71
	WORK ORDER
BY JLP	CHK. BY	DATE

4500°R (4568°R) PLUS 300°R BARREL SECTION

RESULTS: ELEMENT STRAINS

ELEMENT No.	TEMP °F	σ_T	$\frac{E_s}{E_i}$	$E_i \times 10^6$	$\epsilon_T = \frac{\sigma_T}{E_s}$	LOCATION FROM MID-CROWN	ϵ^*_{EFF}
5	1434	-11362	.0361	19.8	-.0159		.0165
4	1356	-12983	.0423	20.4	-.0150		.0156
3	1275	-15731	.049	20.9	-.0154	0°	.0146
2	1192	-16956	.0563	21.5	-.014		.0137
1	1106	-19493	.0630	22.0	-.0141		.0128
10	1425	-11602	.0368	19.9	-.0158		.0164
9	1348	-13777	.0429	20.5	-.0157		.0155
8	1269	-14673	.0495	21.0	-.0141	2.5°	.0146
7	1188	-17653	.0567	21.5	-.0146		.0137
6	1103	-19023	.0634	22.0	-.0136		.0128
40	1391	-12613	.0395	20.1	-.0159		.016
39	1316	-14302	.0455	20.6	-.0153		.0151
38	1237	-15937	.0523	21.2	-.0144	15°	.0142
37	1157	-17792	.0592	21.7	-.0138		.0133
36	1075	-19423	.0662	22.2	-.0132		.0124
70	1285	-16618	.0469	20.7	-.0171		.0152
69	1191	-17147	.0559	21.5	-.0143		.0139
68	1117	-17956	.0624	22.0	-.0131	30°	.0129
67	1063	-18303	.0673	22.4	-.012		.0123
66	984	-18361	.0741	22.8	-.011		.0116
80	1224	-18022	.051	21.3	-.0166		.0148
79	1158	-18800	.0580	21.7	-.0149		.0136
78	1090	-20169	.0649	22.2	-.014	35°	.0123
77	1020	-17611	.0708	22.7	-.011		.0119
76	948	-16332	.0757	23.1	-.009		.0115
90	1166	-20285	.0548	21.6	-.0171		.0143
89	1100	-18433	.0622	22.0	-.0135		.013
88	1031	-23341	.0705	22.6	-.0146	40°	.012
87	961	-17102	.0746	23.0	-.0097		.0113
86	888	-16026	.08	23.5	-.0085		.0112

4500°R (4568°R) PLUS 300°R BARREL SECTION (CONT.)

RESULTS: ELEMENT STRAINS

ELEMENT No.	TEMP °F	σ_T	$\frac{E_S}{E_i}$	$E_i \times 10^6$	$\epsilon_T = \frac{\sigma_T}{E_S}$	LOCATION FROM MID-CROWN	ϵ_{EFF}*
95	1122	-20435	.0579	22.0	-.016	45°	.0139
94	1057	-22672	.0663	22.5	-.0152		.0125
93	989	-18302	.0739	22.9	-.011		.0116
92	920	-20174	.0812	23.3	-.011		.0108
91	847	-15702	.0833	23.8	-.008		.0109
105	993	-22572	.0664	22.7	-.015	52°	.0129
104	929	-23151	.0776	23.3	-.0128		.0113
103	864	-22438	.0889	23.6	-.0109		.0101
102	797	-18608	.0964	24.1	-.008		.0096
101	726	-14141	.0951	24.6	-.006		.0ϕ0
110	915	-23193	.0719	23.4	-.014	55°	.0123
109	855	-29540	.0874	23.7	-.0143		.0104
108	794	-19889	.0986	24.1	-.0084		.0094
107	731	-23628	.1052	24.6	-.0091		.0089
106	665	-10380	.0998	25.0	-.004		.0096
115	831	-26534	.0811	24.0	-.0136	60°	.0112
114	775	-22486	.0942	24.2	-.0099		.0099
113	717	-28730	.1119	24.6	-.010		.0094
112	657	-14894	.1149	25.1	-.0052		.0093
111	594	-13788	.1066	25.6	-.0051		.0091
120	743	-39418	.098	24.5	-.0164	65°	.0096
119	685	-37067	.1171	25.0	-.0127		.0081
118	630	-22078	.1256	25.4	-.007		.0077
117	574	-20938	.1249	25.6	-.0065		.0078
116	516	-4262	.1118	26.1	-.0015		.0087

* THE EFFECTIVE STRESS IS COMPUTED FROM THE FOLLOWING EXPRESSION

$$\sigma_{EFF} = \frac{1}{\sqrt{2}} \sqrt{(\sigma_r - \sigma_z)^2 + (\sigma_r - \sigma_T)^2 + (\sigma_z - \sigma_T)^2 + 6\tau_{rz}^2}$$

THE EFFECTIVE STRAIN IS THE EFFECTIVE STRESS DIVIDED BY THE CURRENT VALUE OF THE SECANT MODULUS

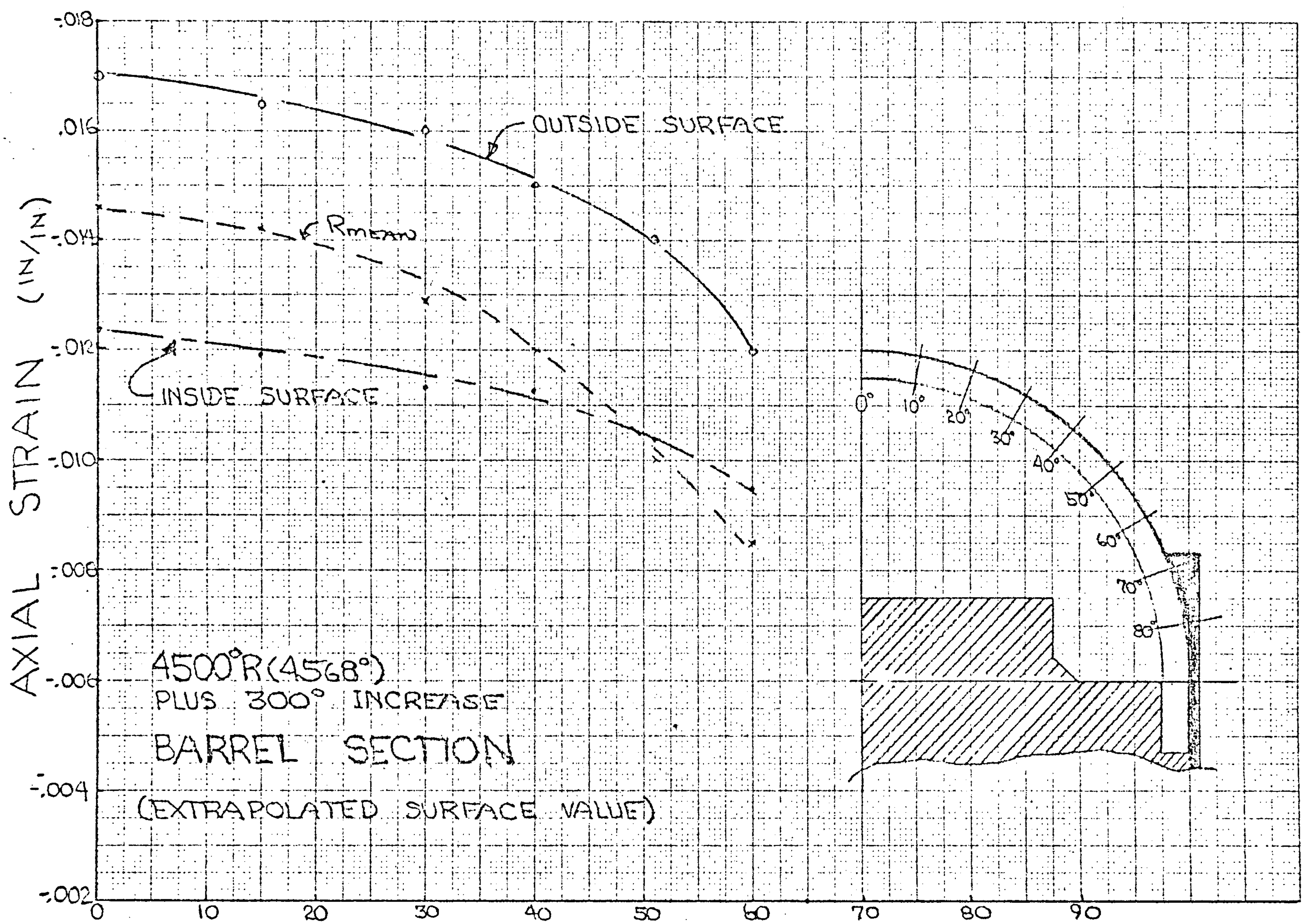
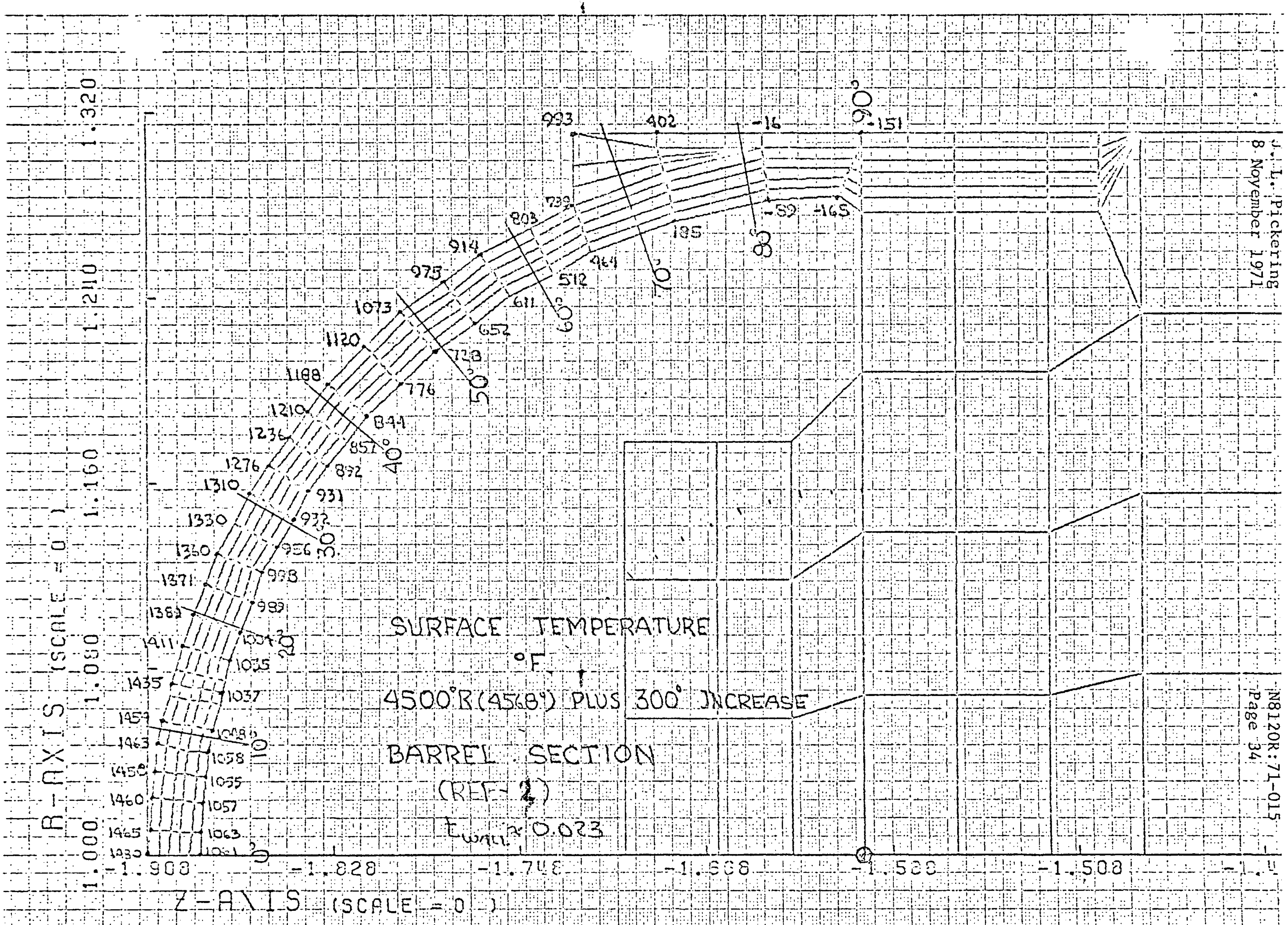


FIG 6. LOCATION FROM CROWN MIDPOINT (DEGREES)



J. L. Pickering
8 November 1971

N8120R:71-015
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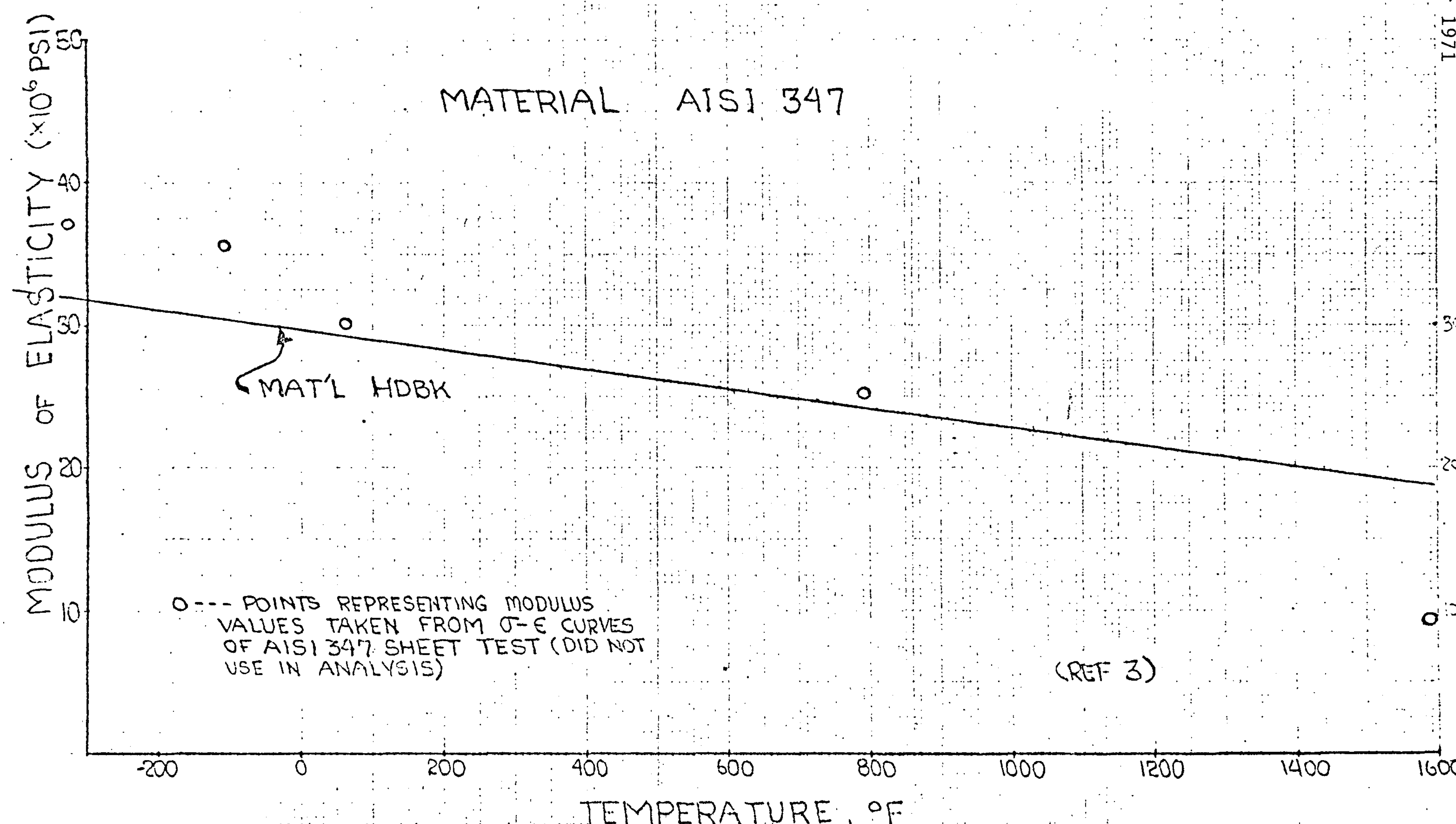
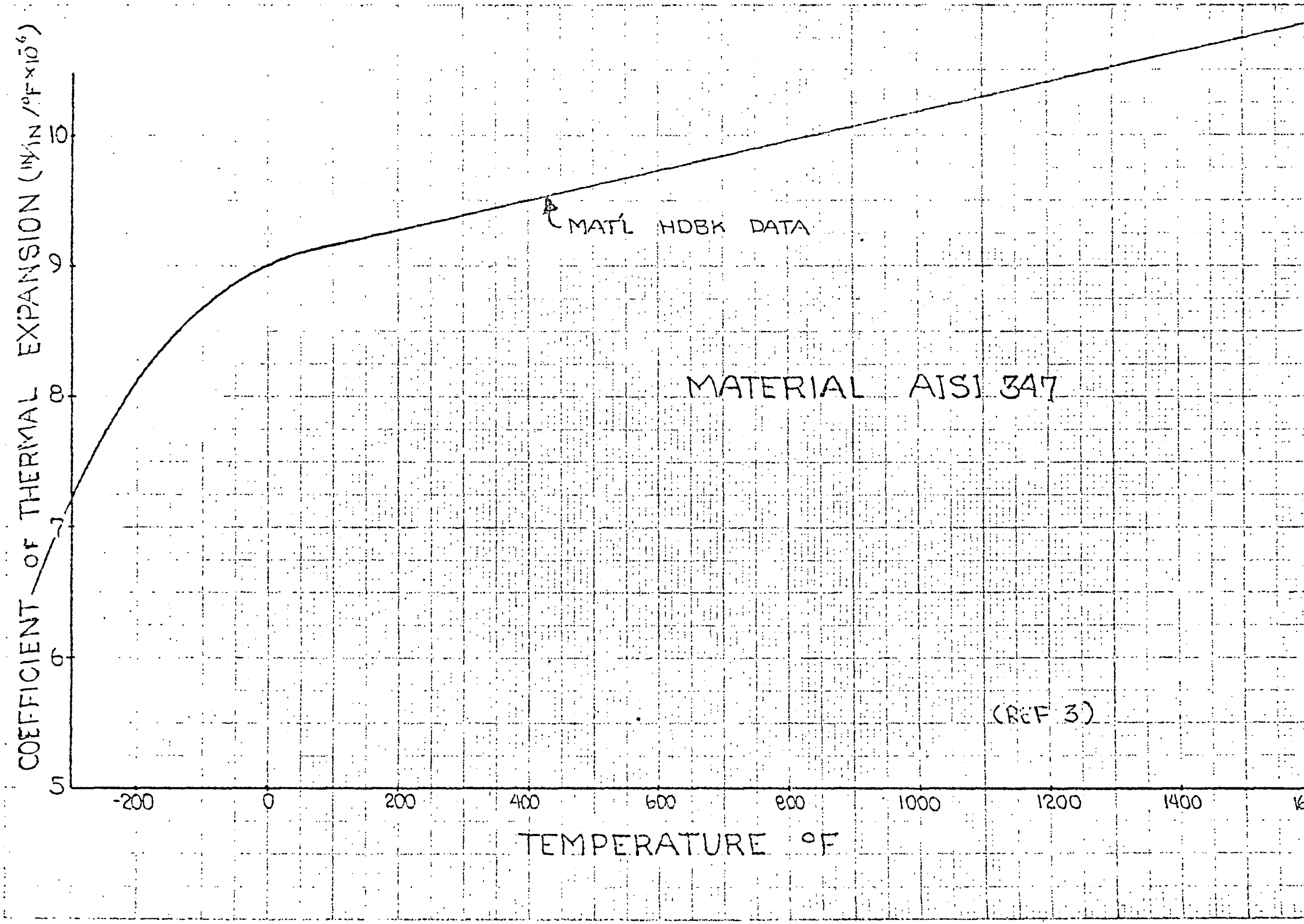
NOZZLE TUBES (BARRE
5/06/71 PLANE ST

VI. MATERIAL PROPERTIES


MATERIAL AISI 347
MODULUS OF ELASTICITY (×10^6 PSI)
50
40
30
20
10
MAT'L HDBK
O --- POINTS REPRESENTING MODULUS VALUES TAKEN FROM σ-ε CURVES OF AISI 347 SHEET TEST (DID NOT USE IN ANALYSIS)
(REF 3)
-200
0
200
400
600
800
1000
1200
1400
1600
TEMPERATURE, °F


COEFFICIENT of THERMAL EXPANSION (IN/IN/°F×10⁻⁶)
10
9
8
7
6
5
-200
0
200
400
600
800
1000
1200
1400
1600
TEMPERATURE °F
MAT'L HDBK DATA
MATERIAL AISI 347
(REF 3)

Enclosure (1)
N8120R:72-032

ENGINEERING OPERATIONS REPORT

Isothermal - Strain Controlled (Compression) -
Low Cycle Fatigue Test of Type 347 Stainless
Steel and Hastelloy X at Elevated Temperatures

Project 141

27 April 1972

J. Larry Pickering

J. Larry Pickering

Approved:

U A Pineda

U. A. Pineda, Supervisor
Applied Mechanics Section
Engineering Staff Department

CLASSIFICATION CATEGORY
Unclassified
U A Pineda 4/27/72
CLASSIFYING OFFICER DATE

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Isothermal - Strain Controlled (Compression) - Low Cycle Fatigue Test of Type 347 Stainless Steel and Hastelloy X at Elevated Temperatures

I. INTRODUCTION

The low-cycle fatigue testing program has been conducted in order to select the best material for the NERVA regeneratively cooled nozzle tubes and develop adequate data to establish design information for the selected material. The test program was conducted in two phases. The first phase (Phase I - Reference 1) utilized three heats of AISI 347 Stainless Steel and two heats of Hastelloy X tested at 1000°F, 1400°F, and 1600°F at the strain range values of 1.5, 3.0 and 5.0 percent using a saw-tooth strain-wave-form (zero to compression type). This phase was used to establish the fatigue response of these two materials and to distinguish which material is the best performer under the tested condition.

The second phase (Phase II) was smaller in scope and was performed to determine hold time effects. The main portion of the Phase II test program used one heat of AISI 347 tested at 1400°F and strain ranges of 1.5, 3.0 and 5.0 percent with a hold time of 10 minutes being introduced at the extreme strain values (compression). Two specimens of Hastelloy X were included under the same condition for comparison purposes as well as other specimens that were tested for general information. This report will review the main points brought out by the Phase I portion of the test program and will be used to introduce and discuss the Phase II results.

II. SUMMARY/CONCLUSIONS

The problem of having to quantify and predict the damage that occurs in the coolant U-tubes of the NERVA nozzle as a result of the start-stop cycles

in the normal steady state operating mode is indeed complex, because of the various parameters that are involved, which are:

1) Temperature
   A) Controls the magnitude of strain
   B) Metallurgical changes

2) Strain Rate (cycle rate)

3) Hold Time

4) Hydrogen Effect, Irradiation Effects

5) Cumulative Effects
   A) Different time combinations
   B) Different temperature combinations

Phase I test program (Reference 1) has been conducted to estimate the effect of some of these parameters and their importance. It should be mentioned, however, that it was not possible to model the U-tubes directly. In fact, isothermal-mechanical strain cycling on cylindrical hour-glass shaped specimens were used not necessarily to simulate the U-tubes but to determine the effect of these parameters on the particular material of the tubes. Therefore, a factor to compensate for this specimen configuration approximation might be necessary for prediction of a crack through condition in the U-tubes.

The Phase II test program can only be considered as a scoping test because of the limited number of specimens tested. However, a relatively high confidence level may be placed on the data by consideration of the knowledge gained in Phase I (heat to heat variation, temperature effect, variation using no-hold strain-wave-forms, etc.).

The application of these data is intended to be used as a portion of the design allowable information for use in calculating a useful life of the NERVA regeneratively cooled nozzle tubes; that is, to establish the useful life of the nozzle tubes without a possible crack through condition under thermal cycling.

A summary of the fatigue tests results of Phase I are illustrated in Figures 1 and 2. A comparison of the mean life response (Figure 1) makes it difficult to discern which material would be the best performer. However, by plotting the 99/95 lines (number of cycles which 99% of the specimens exposed to a particular strain level could be expected to survive with a confidence level of .95), Figure 2, a distinction can be made showing that AISI 347 would have a longer life in the strain range (1.0-2.0%) and temperature range (1000°F-1400°F) of interest. From this comparison AISI 347 was chosen for continued testing.

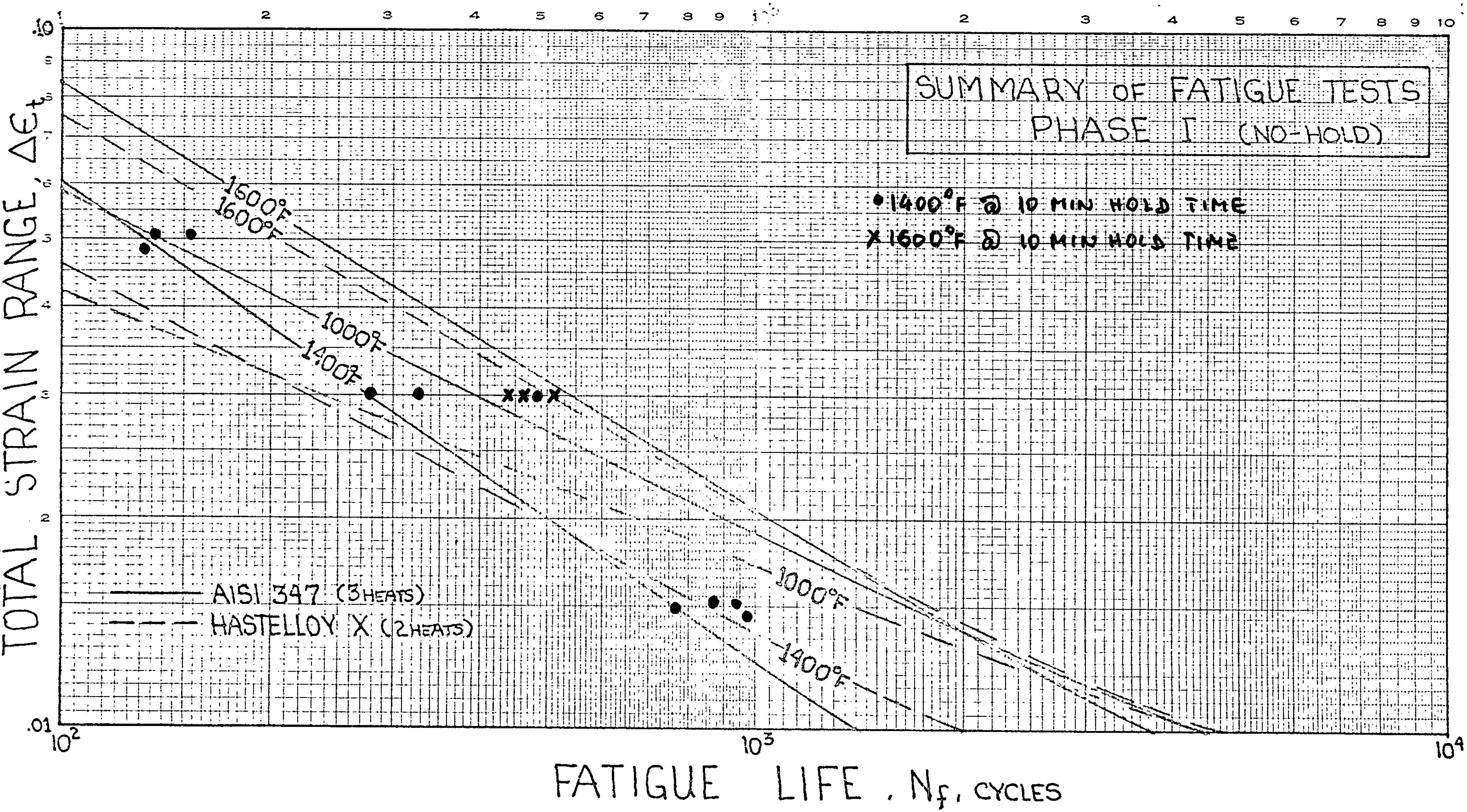


FIGURE 1 COMPARISON OF FATIGUE DATA OF AISI 347 STAINLESS STEEL AND HASTELLOY X FROM THE PHASE I TEST PROGRAM (REF. 1)

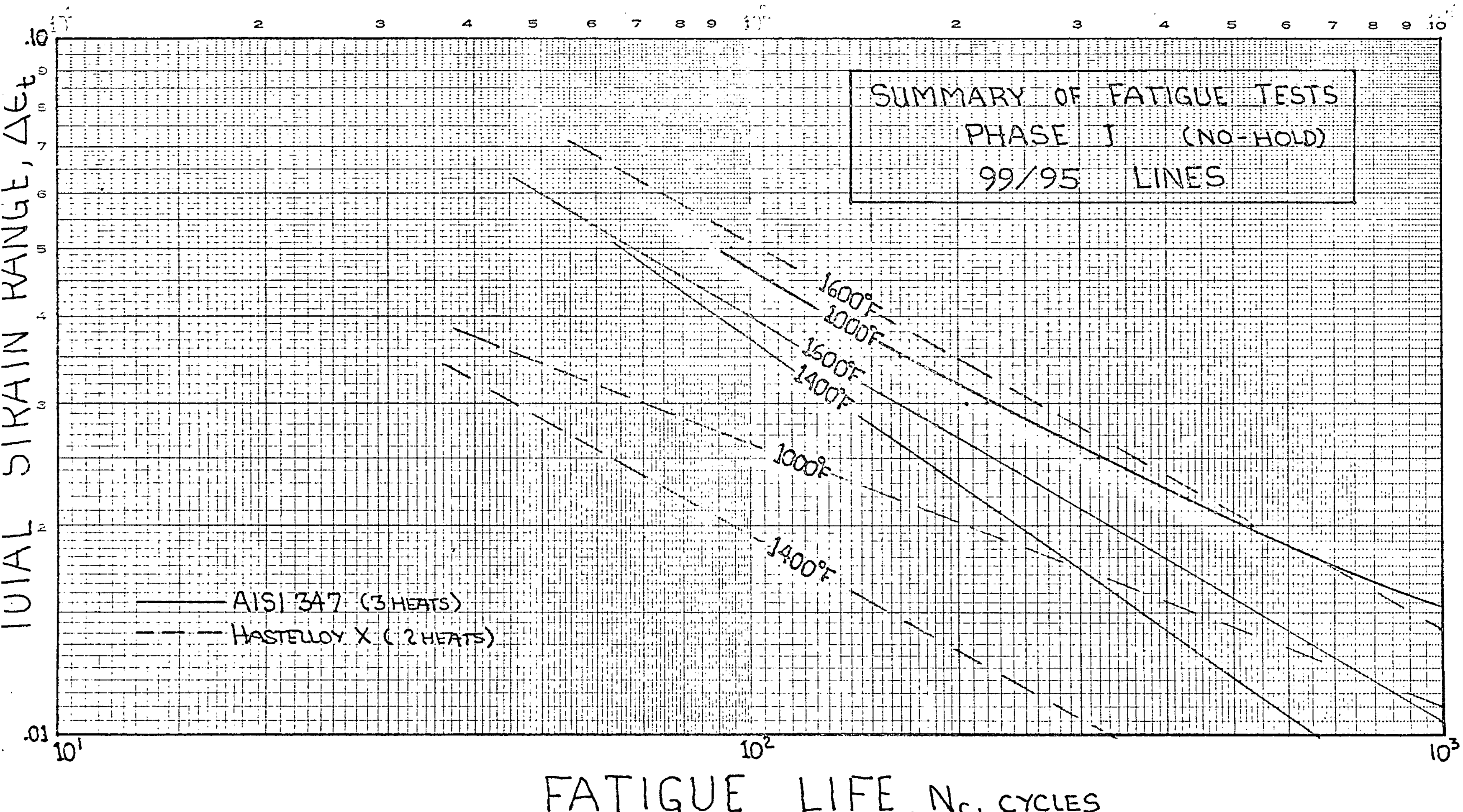


FIGURE 2 COMPARISON OF 99/95 FATIGUE DATA OF AISI 347 AND HASTELLOY X FROM THE PHASE I TEST PROGRAM (REF. 1)

The test results of Phase I indicated that a minimum life condition (with respect to cycles to failure) occurs between 1200° and 1400°F. This result of Phase I was used to structure a portion of the Phase II test program. The remainder of the test matrix incorporated hold periods in the strain-wave-form.

The results of the Phase I and Phase II test program indicated that AISI 347 Stainless Steel had a higher fatigue resistance than Hastelloy X in the operating range of interest and that the data developed utilizing the 10 minute hold-period (in compression) realized a longer life than those incorporating the no-hold strain-wave-form. The design data (99/95 lines) representing the minimum life condition at temperature for the AISI 347 material are represented by the no-hold strain-wave-form tested in the GH_2 environment (Figure 10).

III. TECHNICAL DISCUSSION

A. DISCUSSION OF RESULTS

The test results of Phase I indicated that a minimum life condition (with respect to cycles to failure) occurs between 1200° and 1400°F. This can best be illustrated with the use of Figure 3, where the mean of the fatigue response is plotted for each tested condition as well as the spread around the mean.

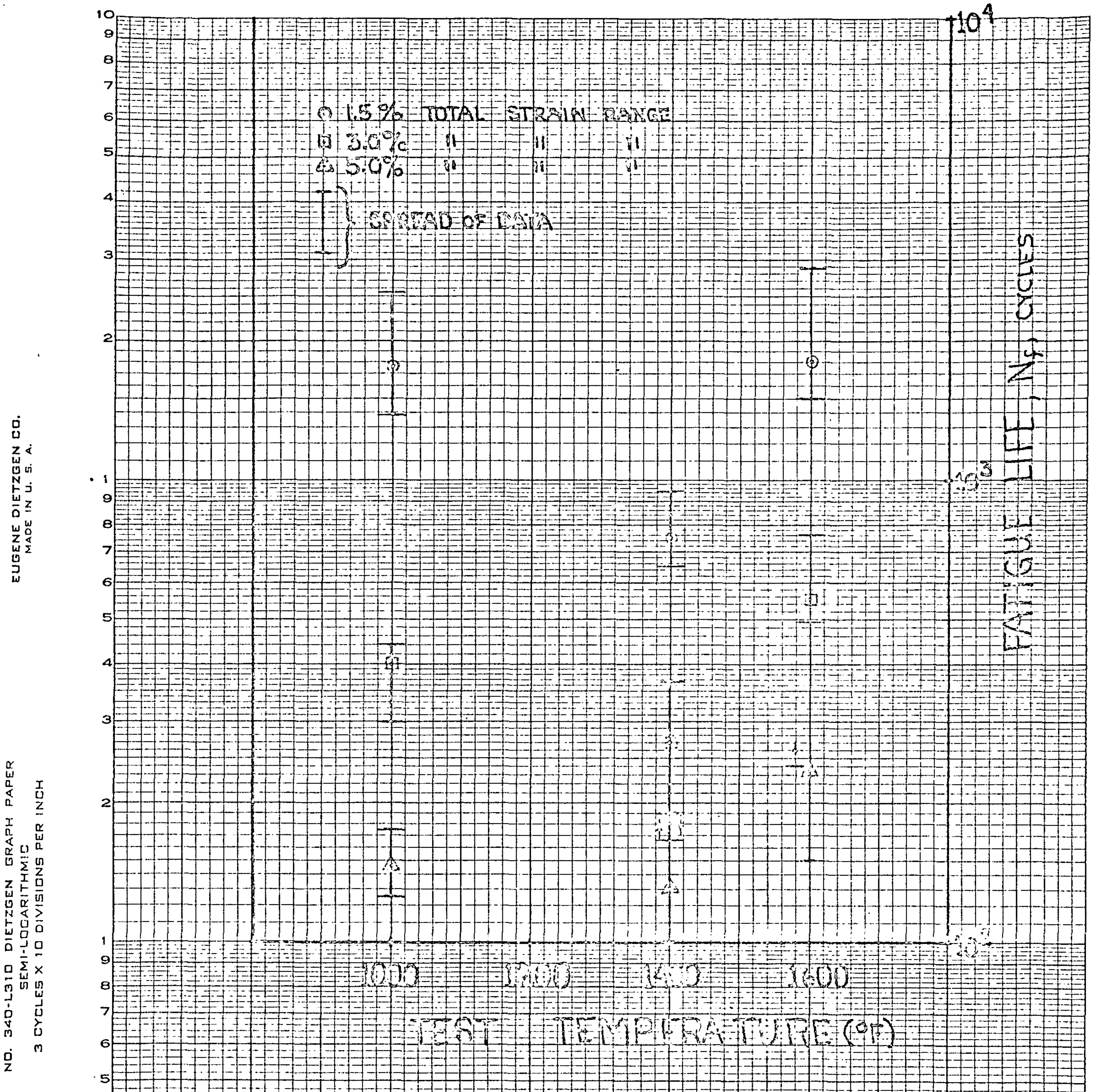


FIGURE 3 COMBINED HEAT DATA (A, B, & C) FOR AISI 347 STAINLESS STEEL PHASE I NO-HOLD (REF 1)

Another notable feature about the Phase I test results concerns the environmental effect on fatigue response. Baseline data was obtained before running the Phase I test program which consisted of both AISI 347 and Hastelloy X being tested in an air environment at 1400°F. This data was used to determine the effect of a gaseous hydrogen environment on the fatigue response of both materials. The relationship between the effect of the two environments can best be observed by using a plastic strain range versus fatigue life (N_f) plot (Figure 4). Both materials have a higher fatigue resistance when operating in the GH_2 environment, however, the environmental effect on Hastelloy X appears to be dependent upon strain range while it is not for AISI 347. A reason for this behavior could be postulated that both materials will show an increase in fatigue resistance while operating in an inert atmosphere, however, Hastelloy X might be more sensitive to a hydrogen embrittlement mechanism which is strain range sensitive. More testing will be required for substantiation of the above statement.

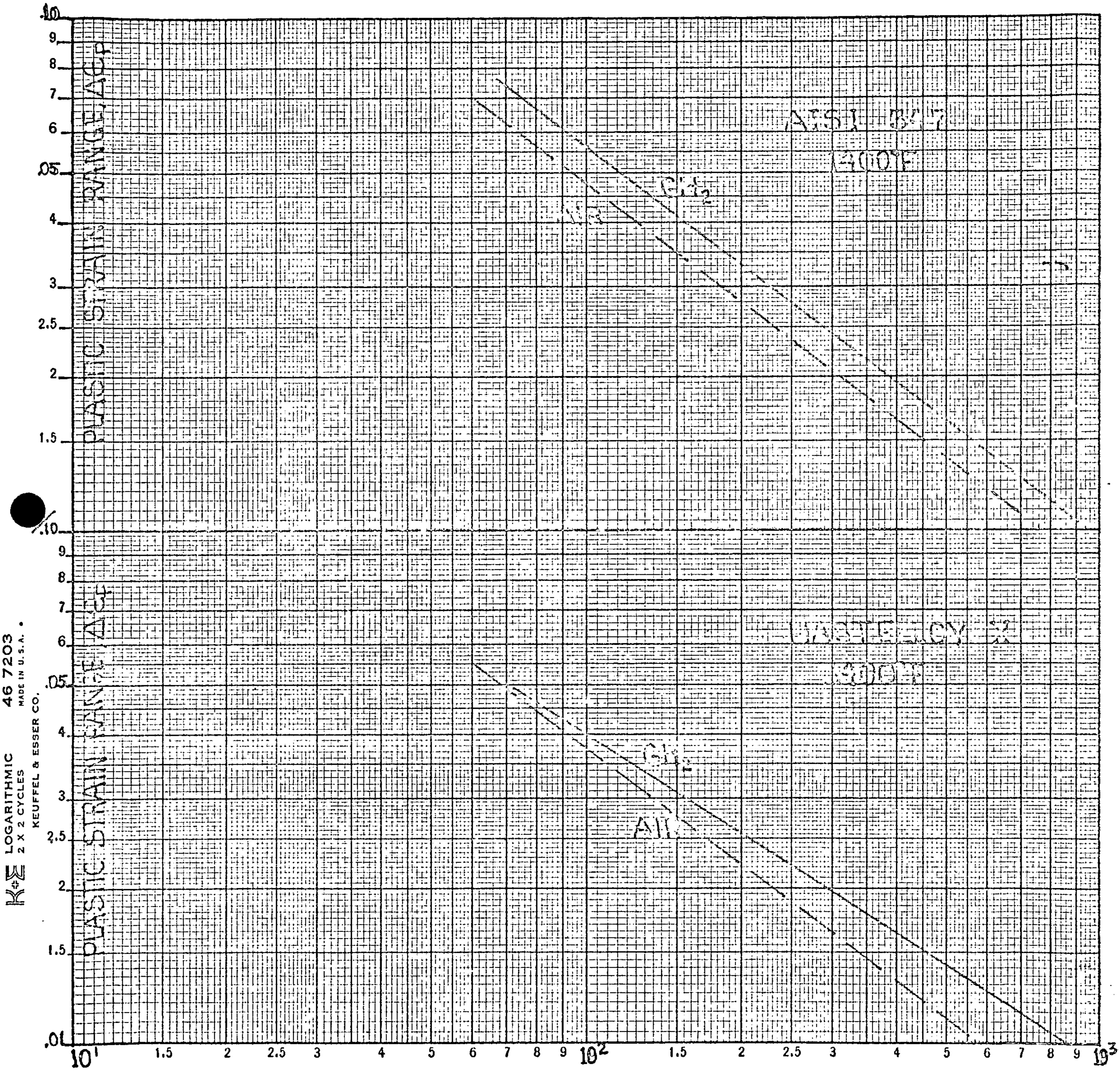


FIGURE 4 COMPARISON OF FATIGUE RESULTS TESTED IN AIR AND GASEOUS HYDROGEN ENVIRONMENTS FOR AISI 347 STAINLESS STEEL AND HASTELLOY X AT 1400°F (REF. 1)

C3

A portion of the Phase II test program introduced hold periods of 10 minutes at the extreme strain range (compression) in the strain-wave-form. The data from this test can be represented by a straight line as illustrated in Figure 5. This data representation is in agreement with that of the no-hold tests (Phase I). The majority of the samples of the Phase II test were structured to establish this line. The test temperature of 1400°F was selected because of the amount of data available for comparison purposes with the Phase I test results. This comparison (Figure 6) brings out a result that is difficult to explain. That is, although there is not enough data to actually establish the Phase II hold time test line, a definite trend of an increased life is apparent over that of the no-hold tests which were conducted in air and the GH_2 environments. This increased life perhaps could be a result of some metallurgical transformation, because normally a decrease in fatigue response occurs with any type of hold introduced in the strain-wave-form.

The results of the Phase II test are shown in Tables II, III and IV, pages 25, 26 and 27.

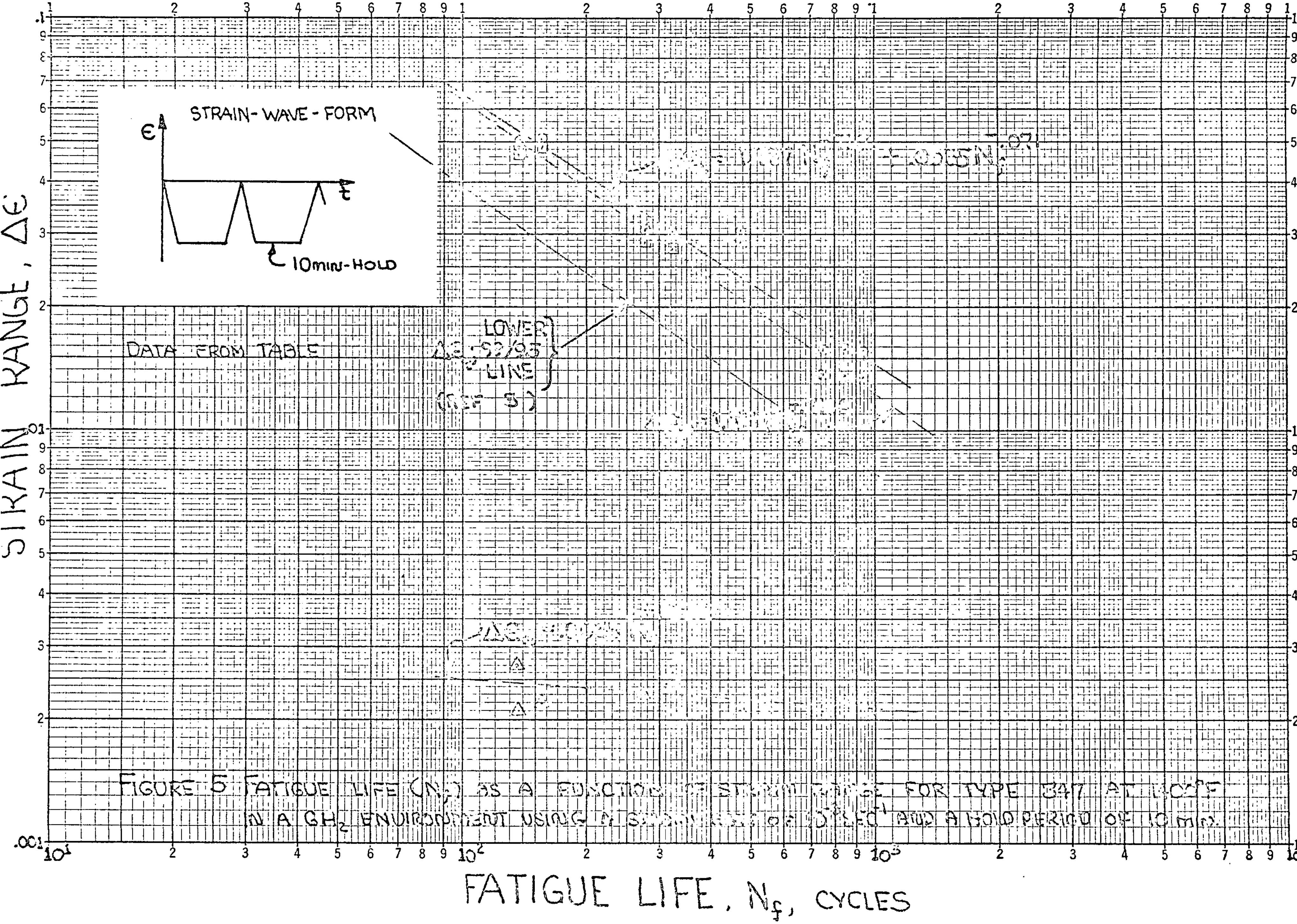


FIGURE 5 FATIGUE LIFE (N_f) AS A FUNCTION OF STRAIN RANGE FOR TYPE 347 AT [illegible]°F IN A GH_2 ENVIRONMENT USING A STRAIN RATE OF 10^{-3} SEC^{-1} AND A HOLD PERIOD OF 10 MIN.

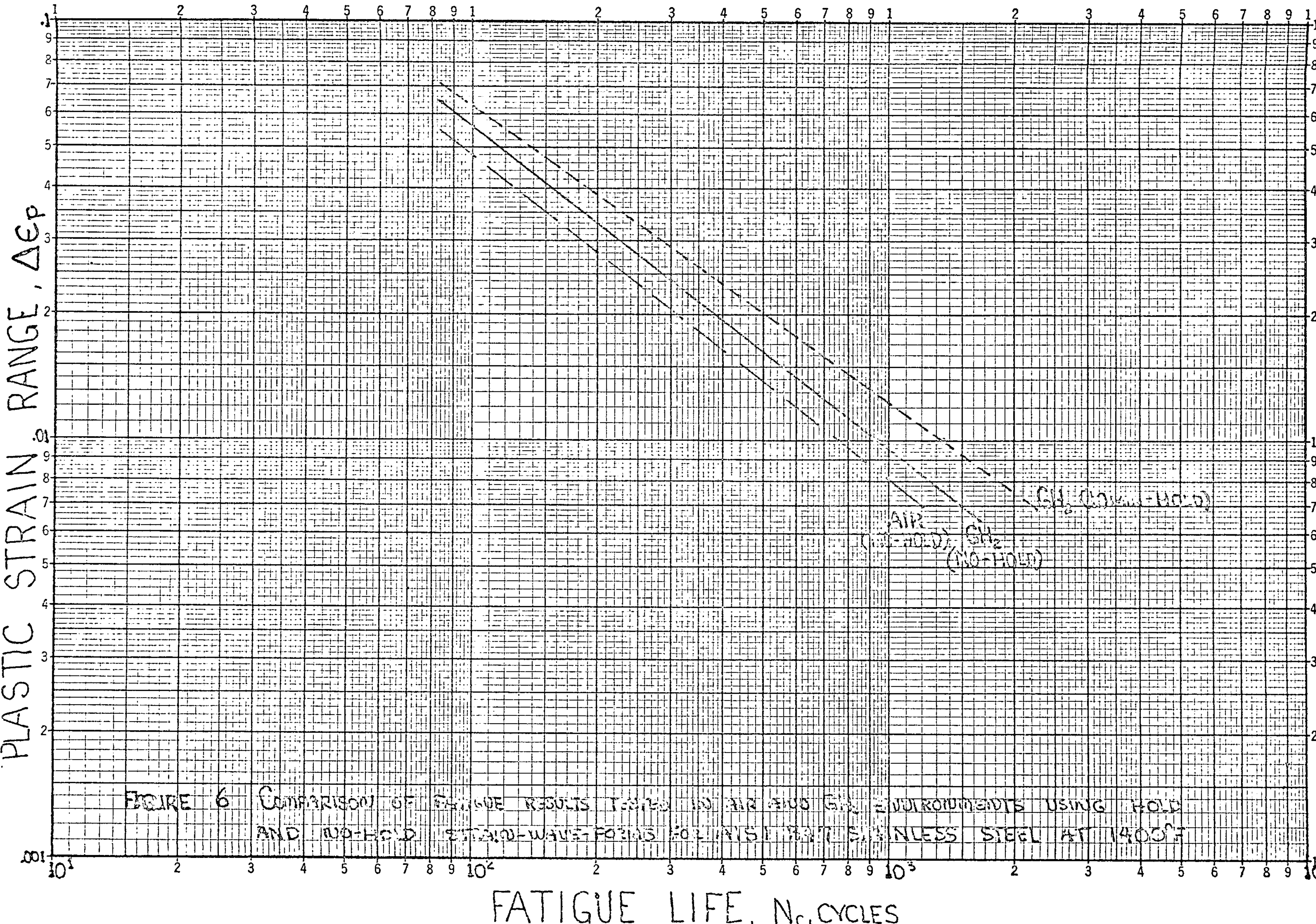


FIGURE 6 COMPARISON OF FATIGUE RESULTS TESTED IN AIR AND GH_2 ENVIRONMENTS USING HOLD AND NO-HOLD STRAIN-WAVE-FORMS FOR AISI 304 STAINLESS STEEL AT 1400°F

Figure 7 illustrates other specimens that were tested with a 10-min-hold period being introduced at the extreme strain valve (compression). Although, there were only three points tested for AISI 347 at 1600°F it appears that hold time (10 min.) is not detrimental at this temperature level either. Two specimens of Hastelloy X were tested at 1600°F and 1400°F using the same 10 min. hold period (Figure 7). It was reported (Reference 2) that severe necking of the specimens occurred during the tests. The cause of this was not explained in the test write-up and is rather difficult to understand, being as the test eas performed using a controlled strain range testing procedure. The results indicate that the effect of the hold period on the Hastelloy X specimens was not much different than the no-hold test. A statement could not be made as to whether or not there was an increase or decrease in fatigue response due to the limited number of samples.

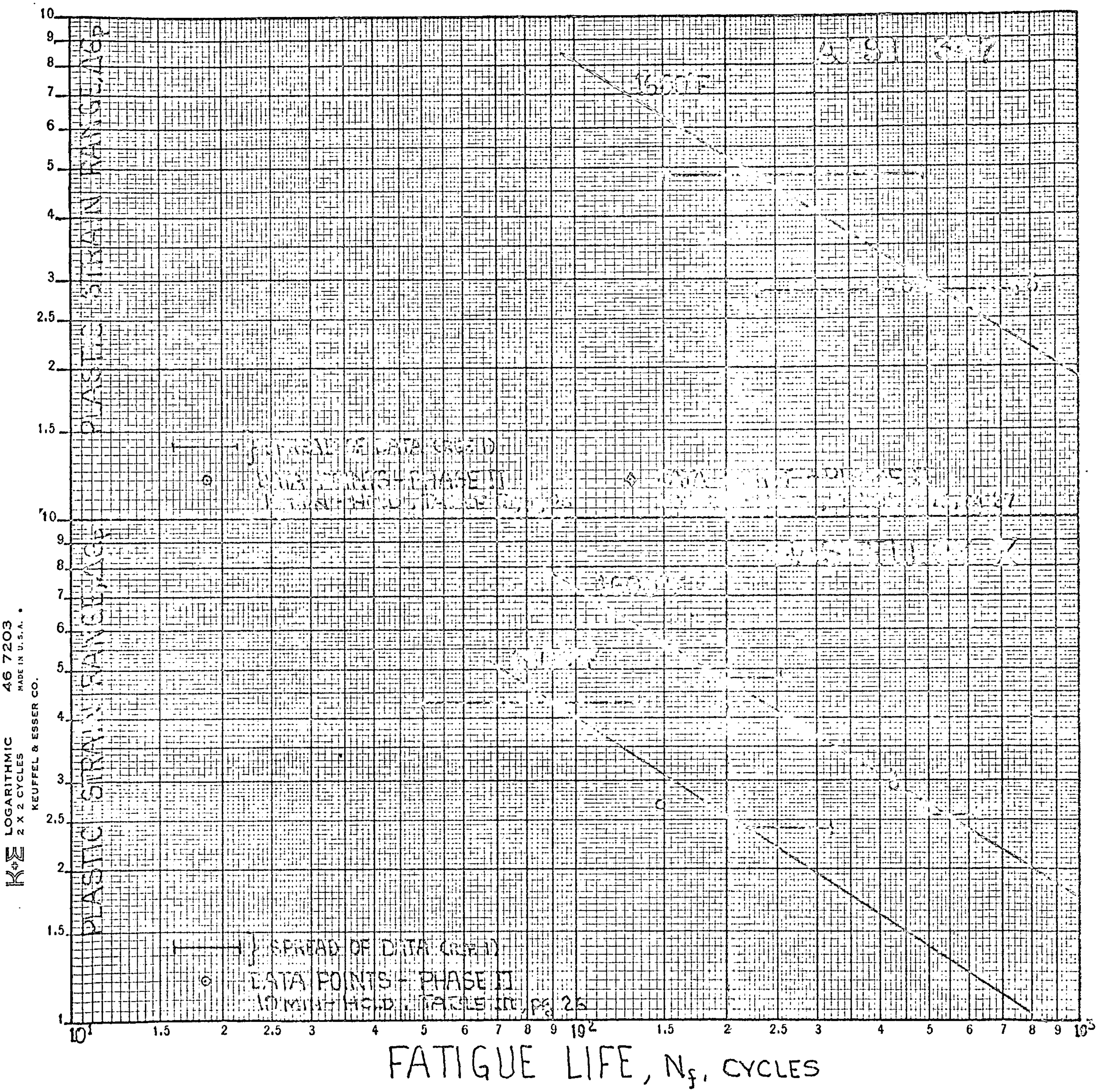


FIGURE 7 COMPARISON OF PHASE I (NO-HOLD) RESULTS TO PHASE II DATA POINTS INCORPORATING 10 MIN-HOLD PERIODS AT THE EXTREEM STRAIN RANGE (COMPRESSION) .... REF 2 & 4

Interpolation of the test data will be necessary in order to be able to describe the fatigue response over the temperature range of interest. This can best be performed on the type of plot used in Figure 3. Figures 8 and 9 illustrate the mean response (and the spread of the extreme data points) of two strain ranges tested in the GH_2 environment at the three elevated temperatures. The curves used to represent the interpolated values indicate that a minimum life condition occurs at about 1300°F for both strain ranges. The data points developed in the Phase II program (Reference 2 and 4) substantiate the assumed interpolated curves at the 3.0 percent strain range, however, the curves appear to be conservative at the 1.5 percent strain range. The three points generated at 1200°F for the 1.5 percent strain range (Figure 8) show no degradation of life from the 1000°F temperature level. The results at the 3.0 percent strain range (Figure 9) indicate a marked reduction in fatigue response at the 1200°F temperature level indicating that the fatigue response might be strain range sensitive at this temperature level (1200°F) with respect to changing the mode of fracture (transgranular to intergranular). There is not enough data to confirm this observance, therefore, the interpolated curves will remain as shown in Figure 8 (on the conservative side) illustrating a fracture mode change at the lower strain range. The 99/95 lines were also drawn by using the same general shape of the interpolated curves between the points developed at the specific strain ranges (Reference 1).

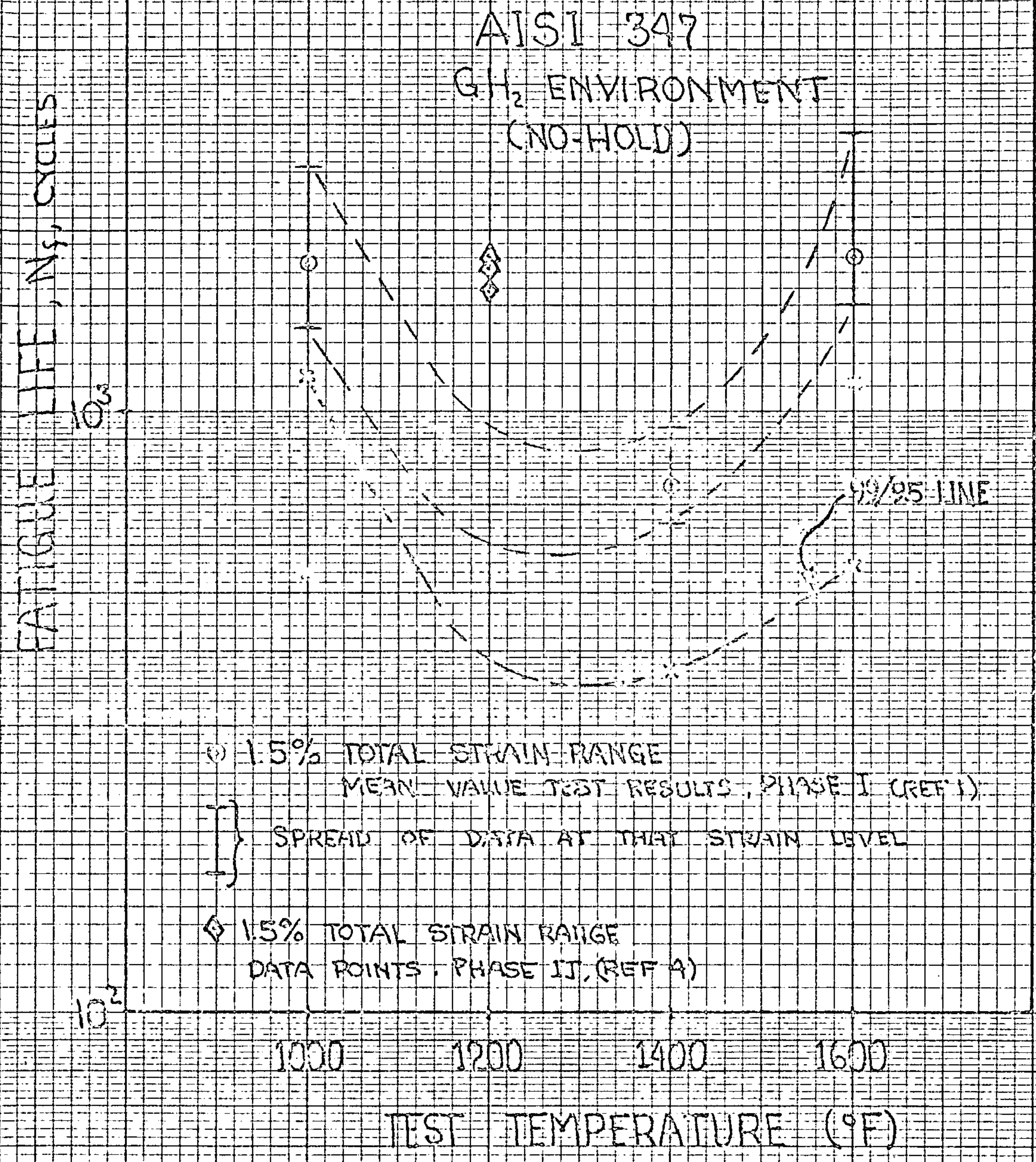


FIGURE 3 FATIGUE LIFE VS TEMPERATURE FOR A TOTAL STRAIN RANGE OF 1.5%, GH_2 ENVIRONMENT (REF 1)

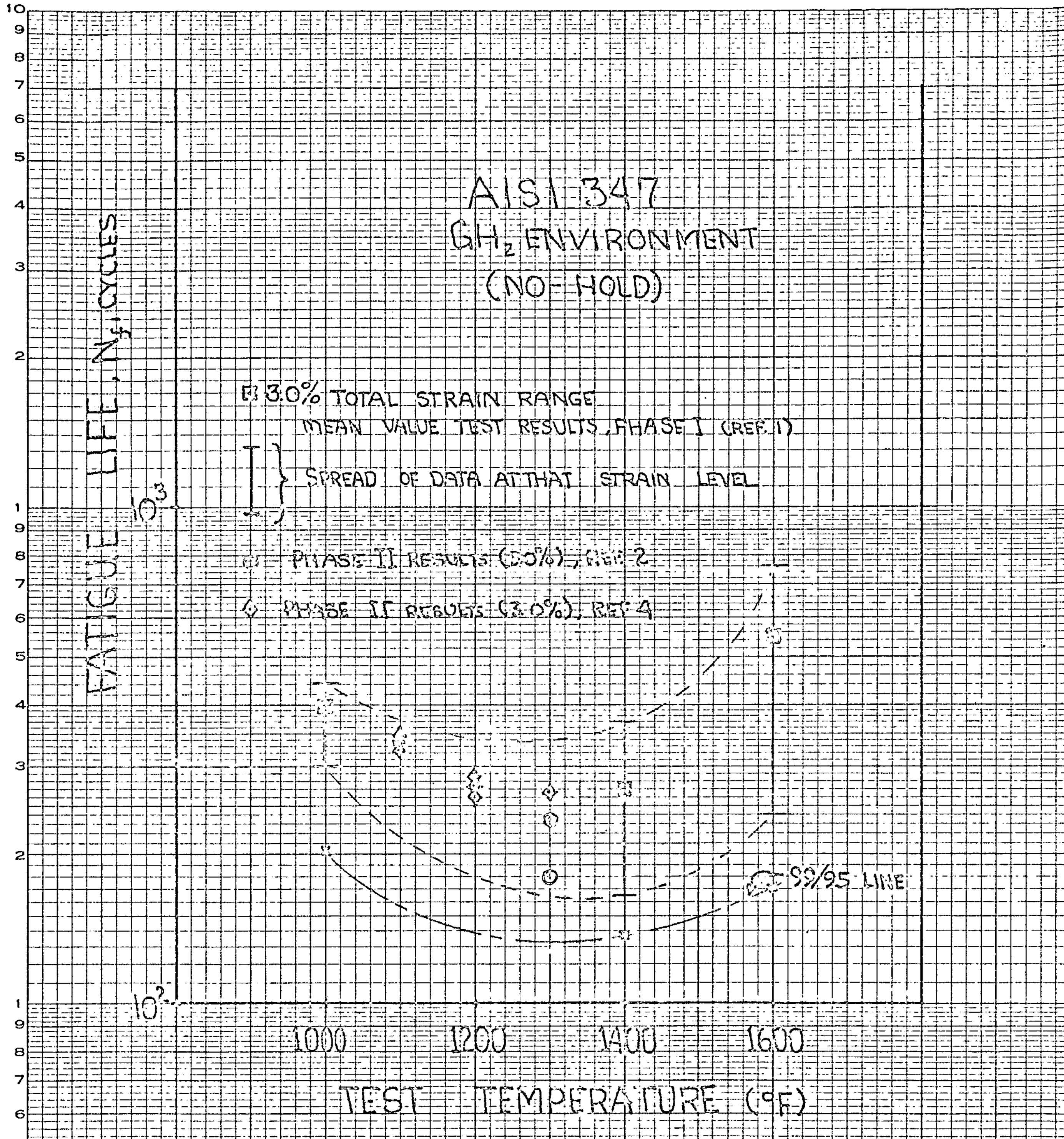


FIGURE 9 FATIGUE LIFE VS TEMPERATURE FOR A TOTAL STRAIN RANGE OF 3.0%, GH_2 ENVIRONMENT

The curves (representing the 99/95 values) that are shown in Figures 8 and 9 were used to obtain the fatigue response at the temperature levels between the tested conditions. These interpolated values are shown in Figure 10 and are represented by straight lines within the range of tested values (1.5% - 3.0%). The extrapolation of these lines below 1.5% should be done with care (what is shown should be conservative, however). These lines represent the lower bound of the no-hold, strain-wave-form tested in the GH_2 environment and should represent the minimum life response for the NERVA nozzle tube material (excluding those samples tested in an air environment; baseline data-Figure 6).

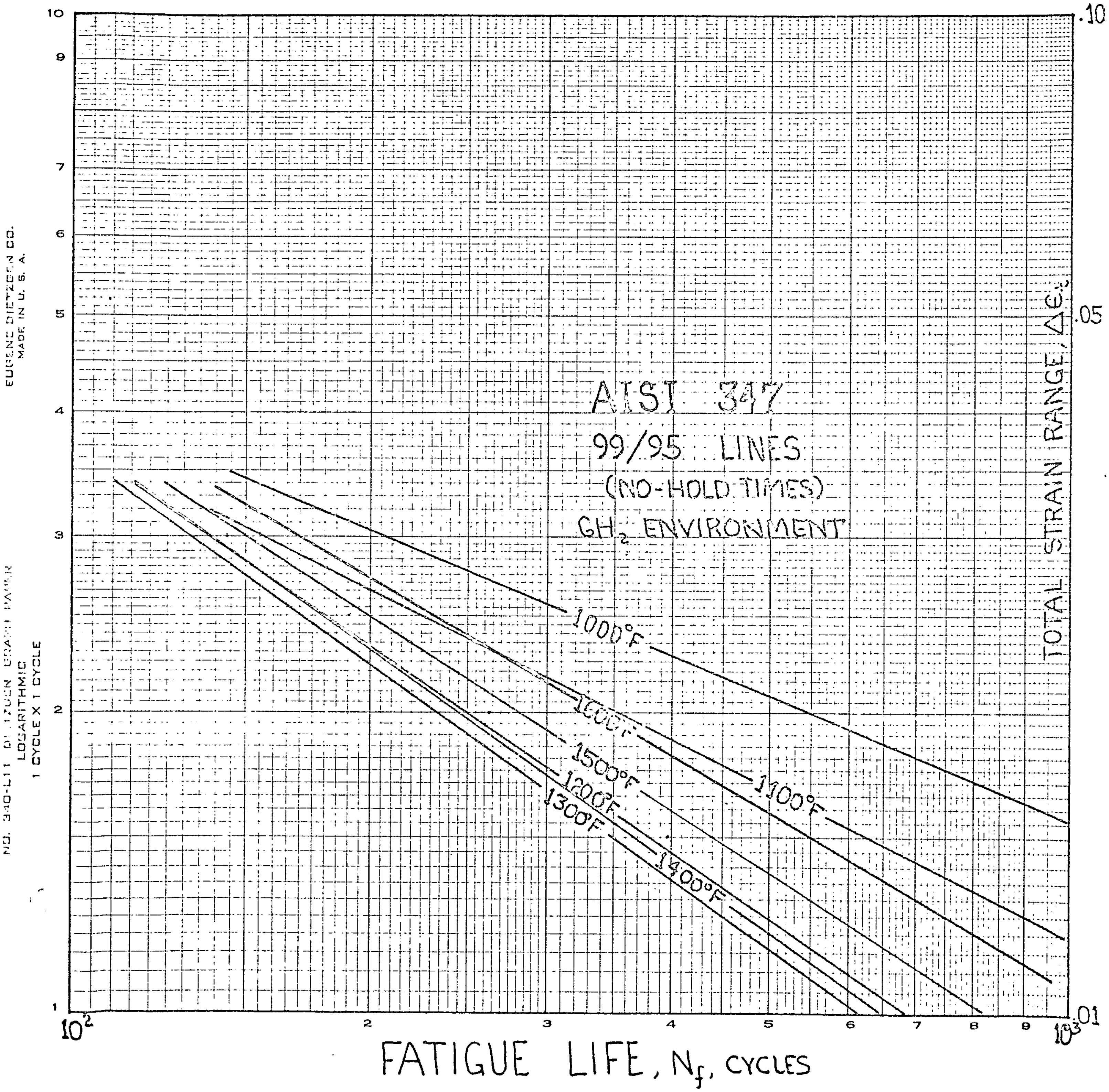
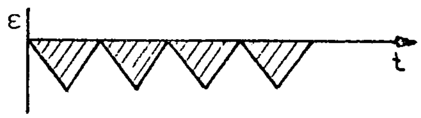
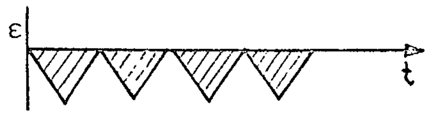
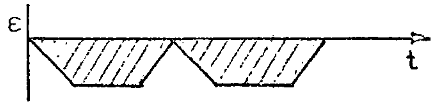
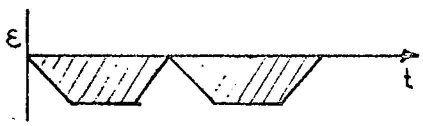
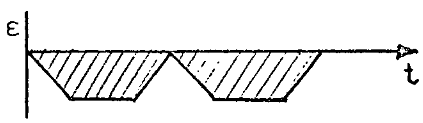
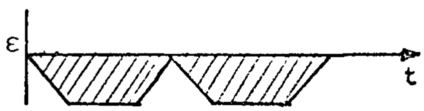


FIGURE 10 FATIGUE LIFE (N_f) VERSUS TOTAL STRAIN RANGE FOR AISI 347 AT TEMPERATURE, PHASE I (NO-HOLD TIMES)

B. TEST PROGRAM

The material, material condition, test matrix, test results, and conclusions for the low-cycle fatigue response of Type 347 Stainless Steel and Hastelloy X in air and gaseous hydrogen under the no-hold condition (Phase I) are listed in Reference 1. The follow-on test matrix (Phase II) includes both hold and no-hold conditions and is listed in Table 1.

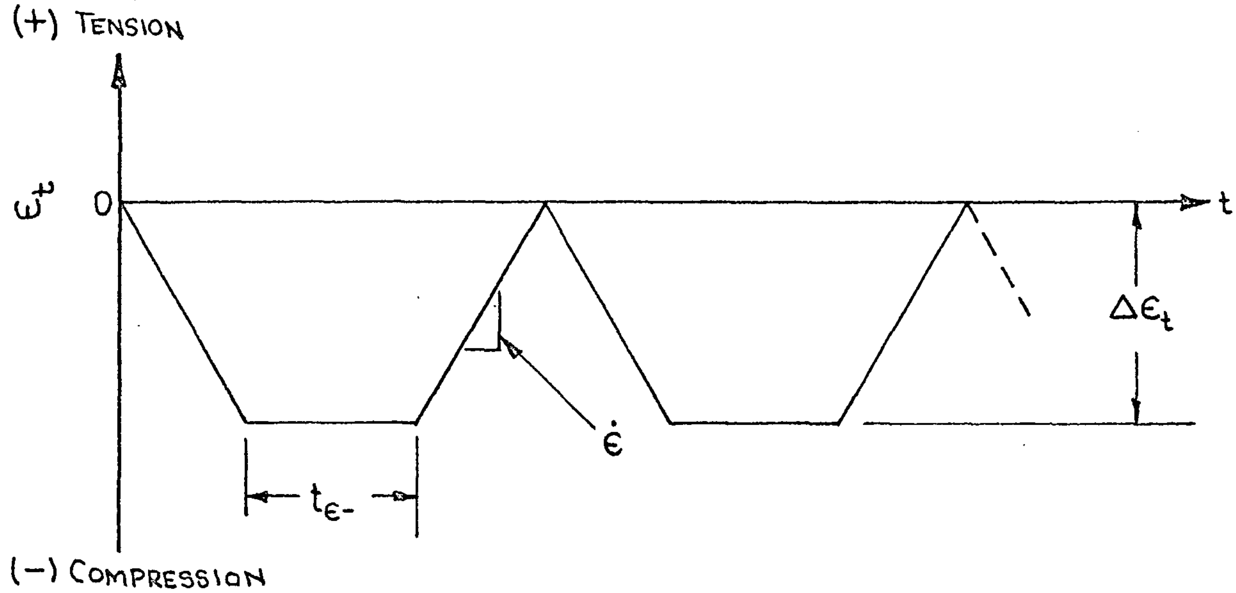
TABLE 1 PHASE II TEST MATRIX
(Reference 2 and 4)

	TEMP (°F)	TOTAL STRAIN $\Delta\varepsilon_t$(%)	STRAIN-WAVE FORM	t_{HOLD} (MIN)	NO. OF SPECIMENS
AISI 347	1100	3.0		0	3
	1200	1.5		0	3
		3.0	"	0	4
	1300	3.0		0	3
	1400	1.5		10	3
		3.0	"	10	3
		5.0	"	10	3
	1600	3.0		10	3
HASTELLOY X	1400	3.0		10	1
	1600	3.0		10	1

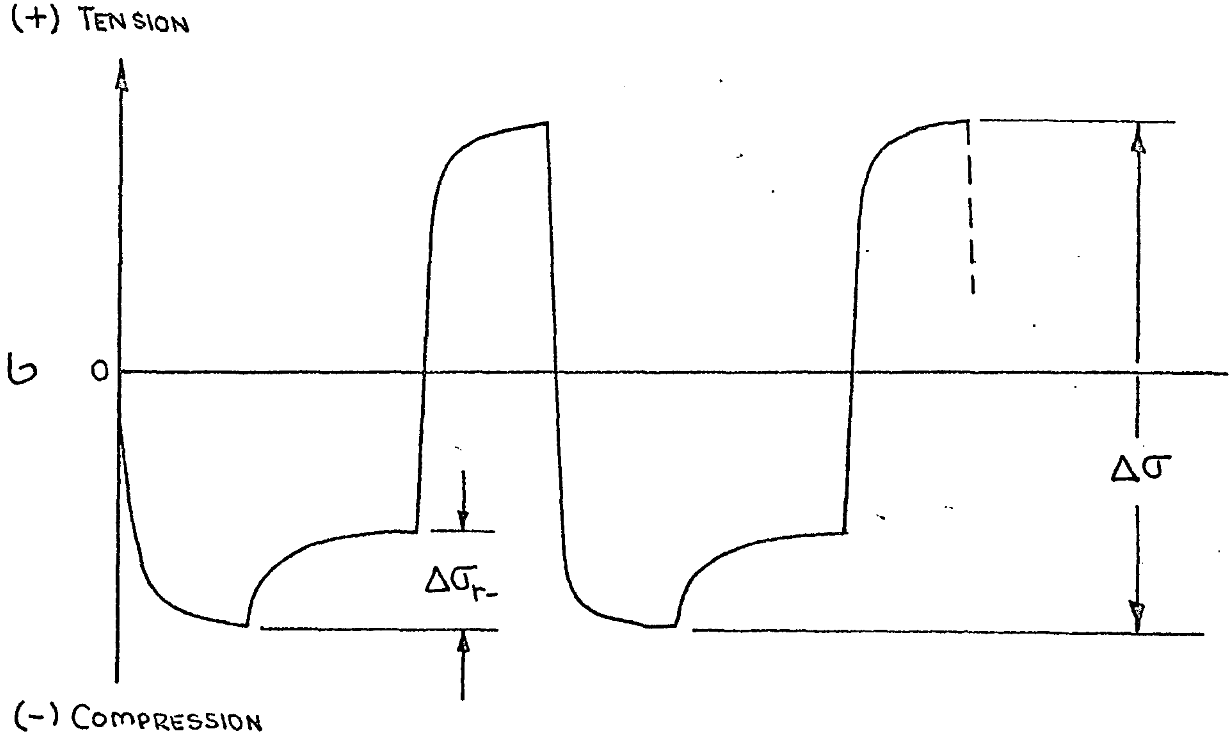
Total number of specimens 27

C. TEST PROCEDURE AND EQUIPMENT

All of the tests were conducted on apparatus identical to that described in Reference 1. The only modification was the addition of timers to the programing equipment so that strain could be held constant for the required hold times. Due to the limited number of specimens only one heat for each material was used. The heat number for AISI 347 was heat X-11585 (A heat) and that for Hastelloy X was heat 2610-0-4007 (D heat). All samples were tested in a gaseous hydrogen environment as described in Reference 1. Figures 11 and 12 contain the nomenclature and wave forms developed in this type of testing.



(a) COMPRESSION STRAIN-WAVE-FORM WITH MAXIMUM STRAIN HOLD TIME



(b) CYCLIC STRESS WAVE FORM

FIGURE 11 CYCLIC WAVEFORMS OF AXIAL STRAIN AND STRESS FOR COMPRESSION STRAIN HOLD-TIME TESTS

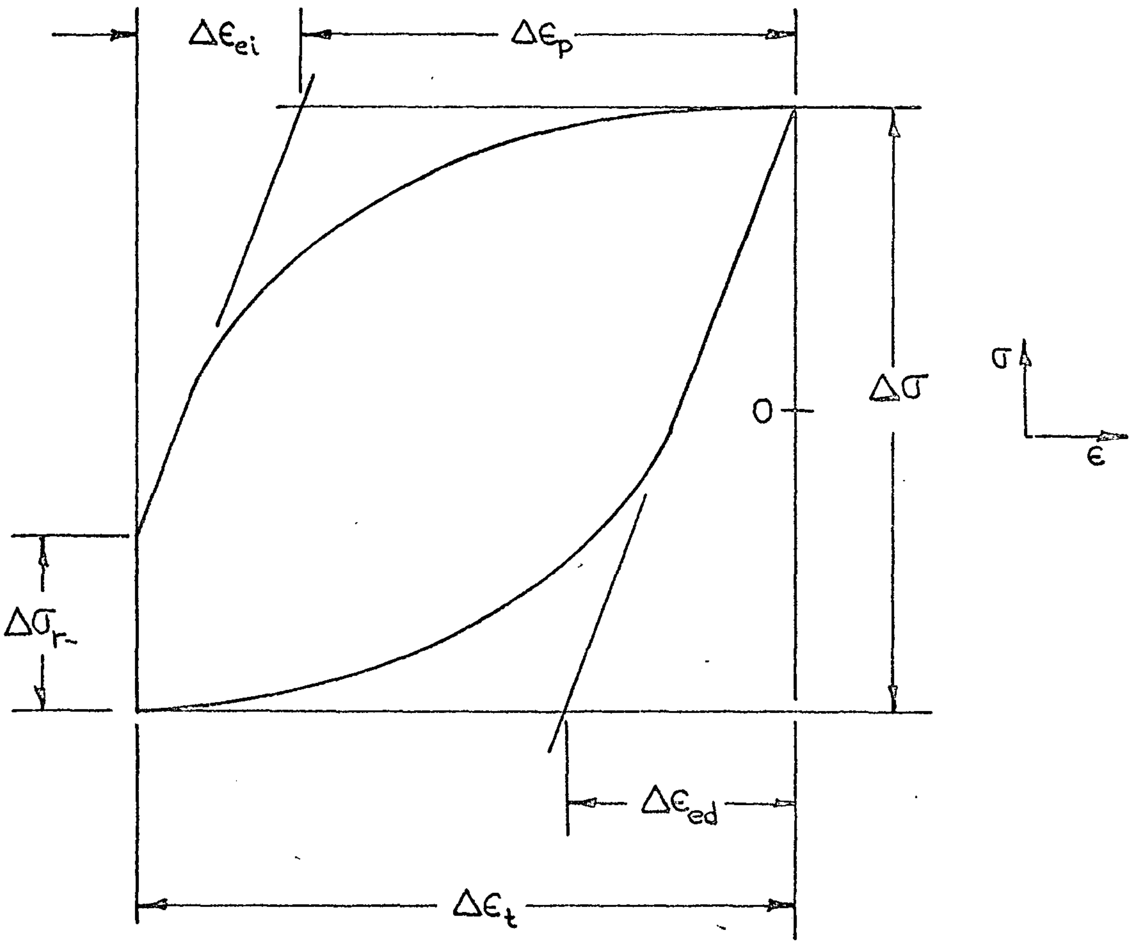


FIGURE 12 TERMS USED TO DEFINE HYSTERESIS LOOPS OF COMPRESSION STRAIN HOLD-TIME TESTS

TABLE II. PHASE II - FATIGUE TEST DATA FOR TYPE 347 STAINLESS STEEL, CONDUCTED IN A PURIFIED HYDROGEN ENVIRONMENT AT 1400 F, WITH A 10-MINUTE MAXIMUM STRAIN HOLD, AND AT AN AXIAL STRAIN RATE OF 10^{-3} SEC^{-1} (REFERENCE 2)

Specimen	Fatigue Life, cycles			Axial Strain Range at $N_f/2$, percent				Stress Range, at $N_f/2$, ksi
						Elastic[(a)]		
	N_f	N_5	N_o	Total	Plastic	$\Delta\varepsilon_{ei}$	$\Delta\varepsilon_{ed}$	
A43	136	124	114	4.85	4.63	0.21	0.32	73.5
A48	137	106	103	5.02	4.75	0.27	0.39	71.0
A44	156	150	122	5.04	4.82	0.22	0.34	63.2
A50	279	275	274	3.08	2.85	0.23	0.36	70.6
A51	322	317	311	3.01	2.76	0.25	0.36	68.2
A46[(b)]	475	---	---	3.08	2.87	0.21	0.32	66.4
A47	746	725	711	1.58	1.37	0.21	0.33	60.9
A45	842	805	789	1.58	1.36	0.22	0.32	61.4
A49	939	845	837	1.55	1.33	0.22	0.34	64.2
A42[(c)]	975	905	885	1.45	1.24	0.21	0.28	57.4

(a) For a symmetric hysteresis loop (no hold time) $\Delta\varepsilon_{ei} = \Delta\varepsilon_{ed} = \Delta\varepsilon_e$.

(b) Values of N_o and N_5 are not reported because the recorder malfunctioned before these values could be determined.

(c) This test was duplicated because the specimen was cycled at a slightly slower strain rate than 10^{-3} sec^{-1}; i.e., $\dot{\varepsilon}$(A42) = 3.4×10^{-4} sec^{-1} and was not included in the analysis.

TABLE III. PHASE II-FATIGUE TESTS FOR TYPE 347 STAINLESS STEEL AND HASTELLOY X, CONDUCTED IN A PURIFIED HYDROGEN ENVIRONMENT AT AN AXIAL STRAIN RATE OF 10^{-3}SEC^{-1} (REFERENCE 2)

Specimen	Hold Time at Maximum Strain (Compression), min	Temperature, F	Axial Strain Range, at $N_f/2$, percent				Stress Range at $N_f/2$, ksi	Fatigue Life, cycles		
			Total	Plastic	Elastic[(a)]					
					$\Delta\varepsilon_{ei}$	$\Delta\varepsilon_{ed}$		N_o	N_5	N_f
A40	0	1300	3.01	2.63	0.38		78.0	177	177	178
A41	0	1300	3.06	2.62	0.44		85.7	---	---	232[(b)]
A52	10	1600	3.06	2.88	0.18	0.19	35.3	---	---	456[(b)]
A53	10	1600	3.00	2.86	0.14	0.20	35.7	---	---	>814[(c)]
D48	10	1400	3.05	2.67	0.38	0.63	134.9	111	130	148
D49	10	1600	3.08	2.91	0.17	0.36	76.2	---	---	>429[(c)]

(a) For a symmetric hysteresis loop (no hold time) $\Delta\varepsilon_{ei} = \Delta\varepsilon_{ed} = \Delta\varepsilon_e$

(b) Values of N_o and N_5 are not reported because the load did not drop before failure occurred.

(c) These values are slightly less than the actual values of N_f (unknown); see explanations in the test.

TABLE IV. PHASE II - FATIGUE TEST DATA FOR TYPE 347 STAINLESS STEEL CONDUCTED IN A PURIFIED HYDROGEN ENVIRONMENT AND AT AN AXIAL STRAIN RATE OF 10^{-3} SEC^{-1} (REFERENCE 4)

Speciman	Hold Time at Maximum Strain (Compression), min	Temperature, F	Fatigue Life, cycles			Axial Strain Range at $N_f/2$, percent				Stress Range at $N_f/2$, ksi
			N_f	N_5	N_o	Total	Plastic	Elastic[a] $\Delta\varepsilon_{ei}$	$\Delta\varepsilon_{ed}$	
A64	--	1100	327	317	308	3.04	2.62	0.42		100.5
A61	--	1100	349	339	332	3.04	2.58	0.46		102.0
A62	--	1100	400	383	367	3.02	2.59	0.43		101.0
A57	--	1200	264	235	205	2.97	2.57	0.40		90.7
A56[b]	--	1200	274	--	-- [c]	2.99	2.56	0.43		88.5
A55	--	1200	281	257	244	2.98	2.59	0.39		88.0
A54	--	1200	381	363	346	2.99	2.58	0.41		93.7
A60	--	1200	1605	1603	1602	1.51	1.18	0.33		75.2
A59	--	1200	1735	1704	1693	1.54	1.20	0.34		75.9
A58	--	1200	1745	1732	1701	1.52	1.21	0.31		72.8
A66[e]	--	1300	269	266	263	3.04	2.69	0.35		72.0
A63	10	1600	506	--	--[c]	2.98	2.88	0.10	0.18	32.1

(a) For a symmetric hysteresis loop (no hold time) $\Delta\varepsilon_{ei} = \Delta\varepsilon_{ed} = \Delta\varepsilon_e$.

(b) This test was duplicated (by Specimen A57) because the specimen was cycled at a strain rate slightly lower than 10^{-3} sec^{-1}; i.e., $\dot{\varepsilon}$ (A56) = 1.644×10^{-4} sec^{-1} for the first 170 cycles.

(c) Values of N_o and N_5 are not reported because the load did not drop before failure occurred.

(e) The data obtained from Specimen A65 was highly irregular; therefore, the test was repeated with Specimen A66.

IV. REFERENCES

1) ANSC Report N8120R:71-013, "Isothermal, Strain Controlled-Low Cycle Fatigue of Type 347 Stainless Steel and Hastelloy X at Elevated Temperatures - Phase I"

2) Letter on ANSC P.O. Number N900105, Compression Low-Cycle Fatigue of Type 347 Stainless Steel and Hastelloy X at Elevated Temperatures, dtd 28 Jan. 1972, to H. Spaletta from Battelle Columbus Laboratories

3) Memorandum N8200:M3096, T. N. Throckmorton to R. G. Ackerman, dtd 22 March 1972, Subj: "Statistical Analysis of Fatigue Test Results for 347 Stainless Steel at 1400°F with a Ten Minute Hold Time"

4) Letter on ANSC P.O. Number N900105, Compression Low-Cycle Fatigue of Type 347 Stainless Steel and Hastelloy X at Elevated Temperatures, dtd April 17, 1972, to P. Dessau from Battelle Columbus Laboratories.

APPENDIX E

RELIABILITY ANALYSIS

NOZZLE FLANGE STRUCTURAL FAILURE MODES

i

ENGINEERING OPERATIONS REPORT

Reliability Analysis
of the
Nozzle Flange Structural Failure Modes

Project 141
Work Statement No. 14

April 1972

R. G. Ackerman
R. G. Ackerman
Nozzle, Pressure Vessel Section

Approved by:
L. A. Shurley
L. A. Shurley, Manager
Nozzle, Pressure Vessel and
Nozzle Extension Department

TABLE OF CONTENTS

I. INTRODUCTION

A preliminary analysis has been conducted on the 2.0 inch thick nozzle/P.V. flange and related failure mechanisms. The nozzle configuration is shown in drawing number 1138000D (Reference (a)). The potential failure mechanisms are identified in the nozzle failure mode analysis which was transmitted to SNSO-C by ANSC Memorandum 7750:M1084 dtd 30 April 1970. This FMA is divided into 6 sections. Each section contains a complete mode of failure. This report will document the results of the analysis of failure mode VIII, called "Failure to Close the Aft End of the Pressure Vessel or to Support the Nuclear Subsystem."

A previous analysis was conducted on this same mechanism in 1971, and reported in N8500:R-005 titled "75K Nozzle/P.V. Joint Interim Design Report. Since that report was within, the flange was reduced in thickness from 2.4 to 2 inches, the jacket wall was reduced from 0.88 inches to 0.66 inches, and more realistic material yield strength values are being assumed.

II. SUMMARY AND CONCLUSIONS

Nozzle flange area preliminary structural reliability calculations have been completed for the 2.0 inch Armco 22-13-5 flange with a 0.66 inch thick jacket wall, and upgraded material properties.

The method of calculation was similar to previous analysis where stress variability was determined using the P.E.T.S. program to determine nominal and maximum stress (Reference (e)). The mean stress was obtained from a finite element computer program (Reference (b)), and materials data was based on a preliminary screening program for Armco 22-13-5 (Reference (d)). Material variation was assumed to be 6.6% of the mean. Reliability was based on a sample size of 20, and 90% confidence level.

The results of the analysis are summarized below:

FMA VIII Nozzle Forms Aft Closure for P.V. & Supports Core		Margin of Safety	Calculated Reliability	Allocated Reliability
A. Lands between bolt holes		.80	$.9_{20}$	$.9_{10}8$
B. Shear lip		.58	$.9_{17}$	$.9_{10}8$
C. Nozzle P.V. Bolts				
Leakage	(Flange Separation)	-	$.9_{7}6$	$.9_{7}$
Structural		.01	$.9_{11}5$	$.9_{10}8$
D. Jacket membrane	(Hoop Stress)	.36	$.9_{11}4$	$.9_{10}8$
	(Meridional)	.56	$.9_{18}4$	$.9_{10}8$
E. Core Support		.37	$.9_{8}63$	$.9_{10}8$

It can be concluded that all failure mechanisms except the core support exceed the reliability allocation. The core support is very close to meeting the allocation and minor changes in stress or strength will make the design acceptable. Therefore the nozzle flange design defined in drawing 1138000D is believed to be an acceptable design. It must be recognized however, that much more remains to be done especially in the area of materials testing before the design can be released for fabrication.

III. TECHNICAL DISCUSSION

A. CONFIGURATION DESCRIPTION

This analysis was conducted on the 2.0 inch flange shown in Figure 1 using the dimensions shown in the nozzle drawing 1138000D (Reference (a)). This configuration utilizes 216 coolant tubes and 108 cooled pressure vessel/nozzle bolts. Coolant holes through the flange supply coolant to the bolt, and reduce the flange temperature. Only one nozzle/P.V. seal is used in this design while previous designs used two seals, one on each side of the bolts.

This analysis is restricted to five points in the nozzle flange area which the finite element stress program have indicated to be points of maximum stress. These points, as indicated in Figure 1, are the shear lip, between the bolts, the core support, the bolts, and the jacket membrane.

B. LOADING CONDITIONS

The maximum stress values were calculated based on the loads shown below and in the August 1971 issue of Engine Specification CP090290C for normal operation at end of life. The maximum loads shown below were used in the finite element stress analysis to calculate maximum stress. The maximum stress values were then reduced by 3 sigma to establish a mean stress for reliability calculations. The load values shown below as PETS program inputs were used to determine maximum and nominal stress for the purpose of determining the sigma variation.

The maximum loads used for the finite element stress analysis to determine maximum stress, (Reference (b)) are as follows:

Core Load	1,110,150 lb.
Chamber Pressure	455 PSI
Coolant Pressure at Nozzle Outlet	1245 PSI
Coolant Pressure at Extension Shield Outlet	1176 PSI

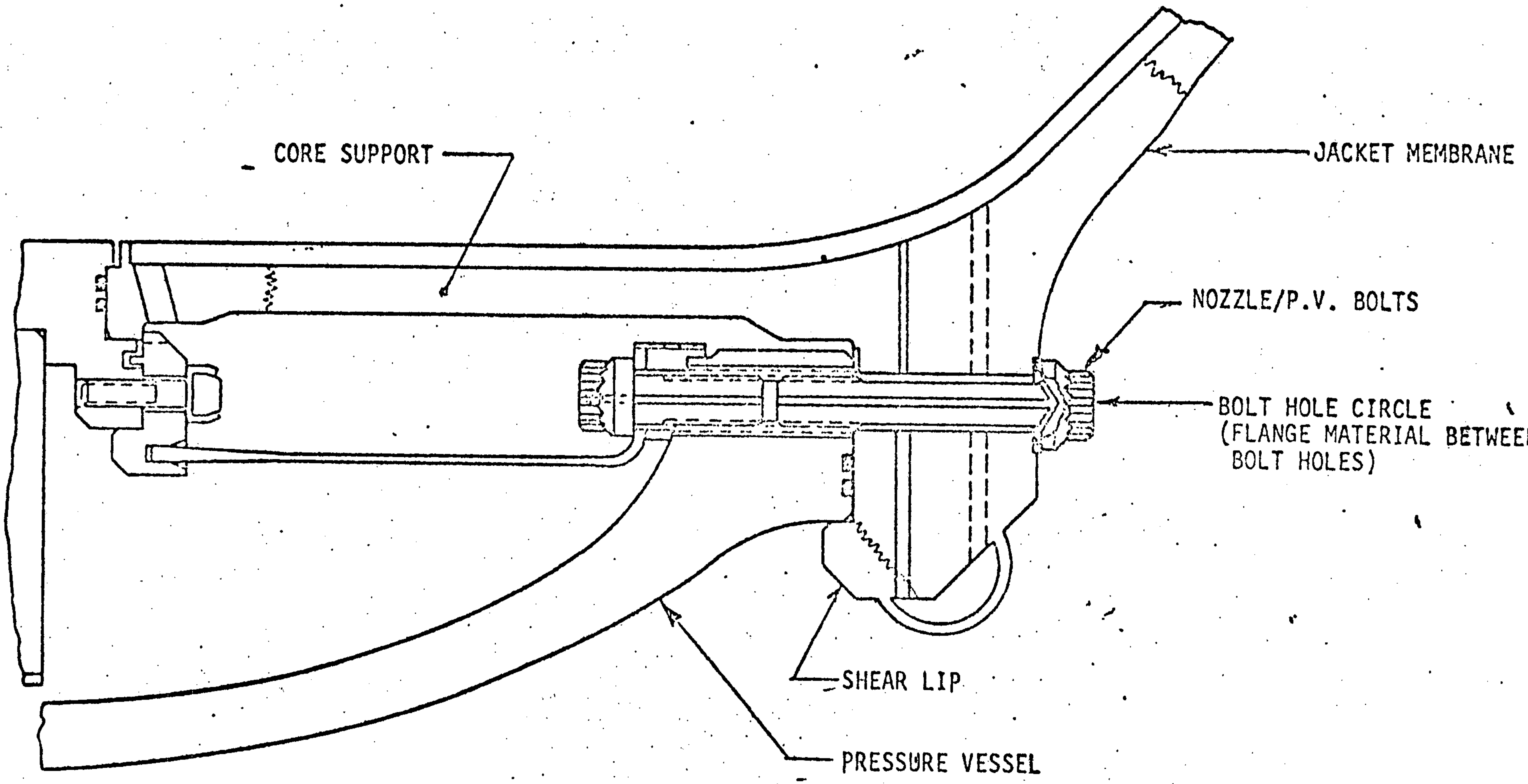
The corresponding values used in late 1970 in the PETS program to calculate stress variation are as follows: (Reference (e))

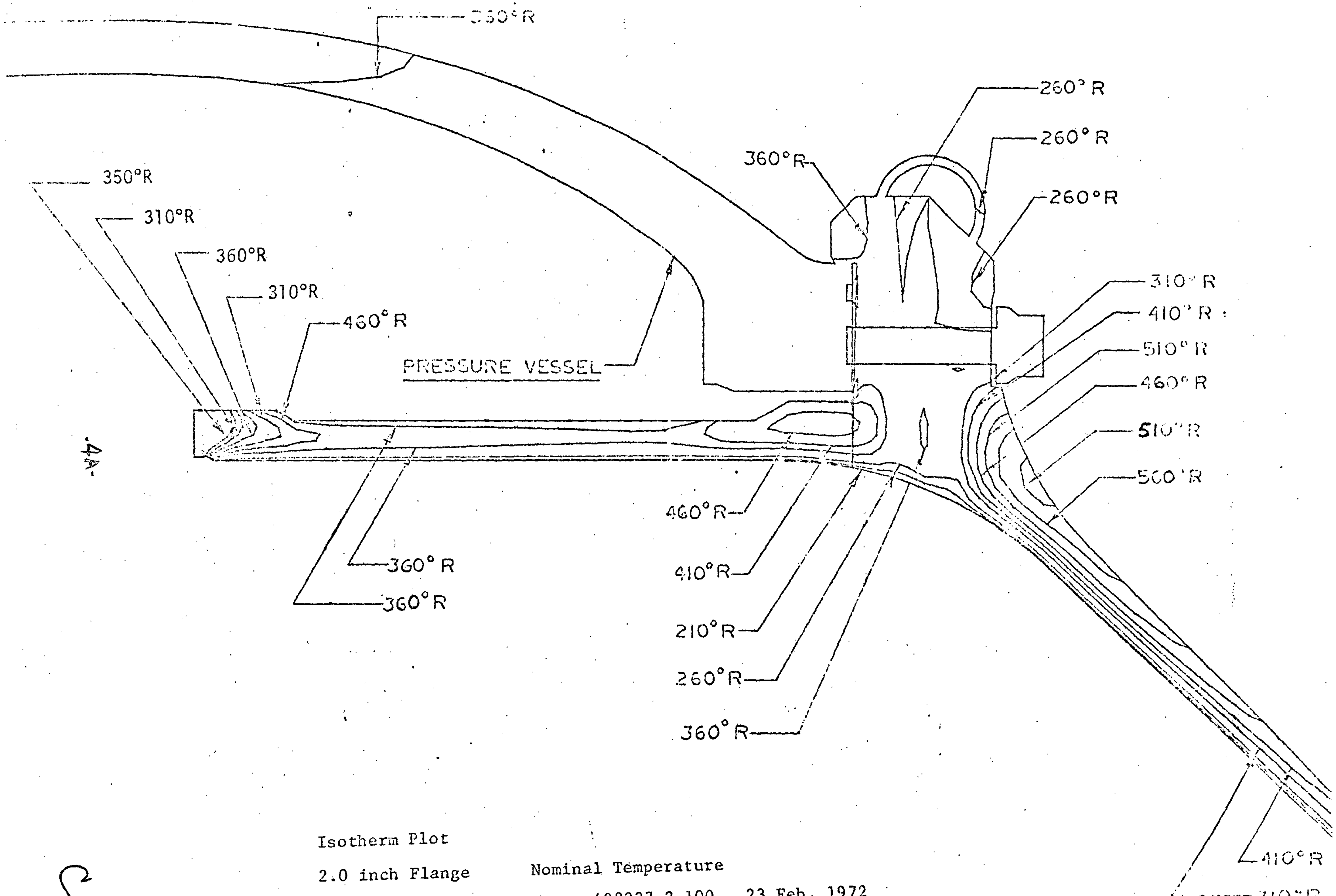
	Nominal	Maximum
Core Load	857,588 lb.	982,665 lb
Chamber Pressure	451 PSI	459 PSI
Coolant Pressure at Nozzle Outlet	1175 PSI	1215 PSI

C. MATERIAL PROPERTIES

Armco 22-13-5 stainless steel is used for all the calculations in this report.

NERVA NOZZLE/P.V. FLANGE, AND
NOZZLE CORE SUPPORT





Isotherm Plot

2.0 inch Flange — Nominal Temperature

Ref. Computer Run — Joe: 428237,2,100 — 23 Feb. 1972

The yield strength values used in this analysis are based on an assumed mean room temperature value of 48 ksi (Reference (d)). The curves are extrapolated from the initial screening program conducted in 1970 and reported in Memo N4350:MM70-448 dtd 22 Dec 1970. The material variation (D_S) was assumed to be 6.6% of the mean since insufficient actual test is available to establish a variation.

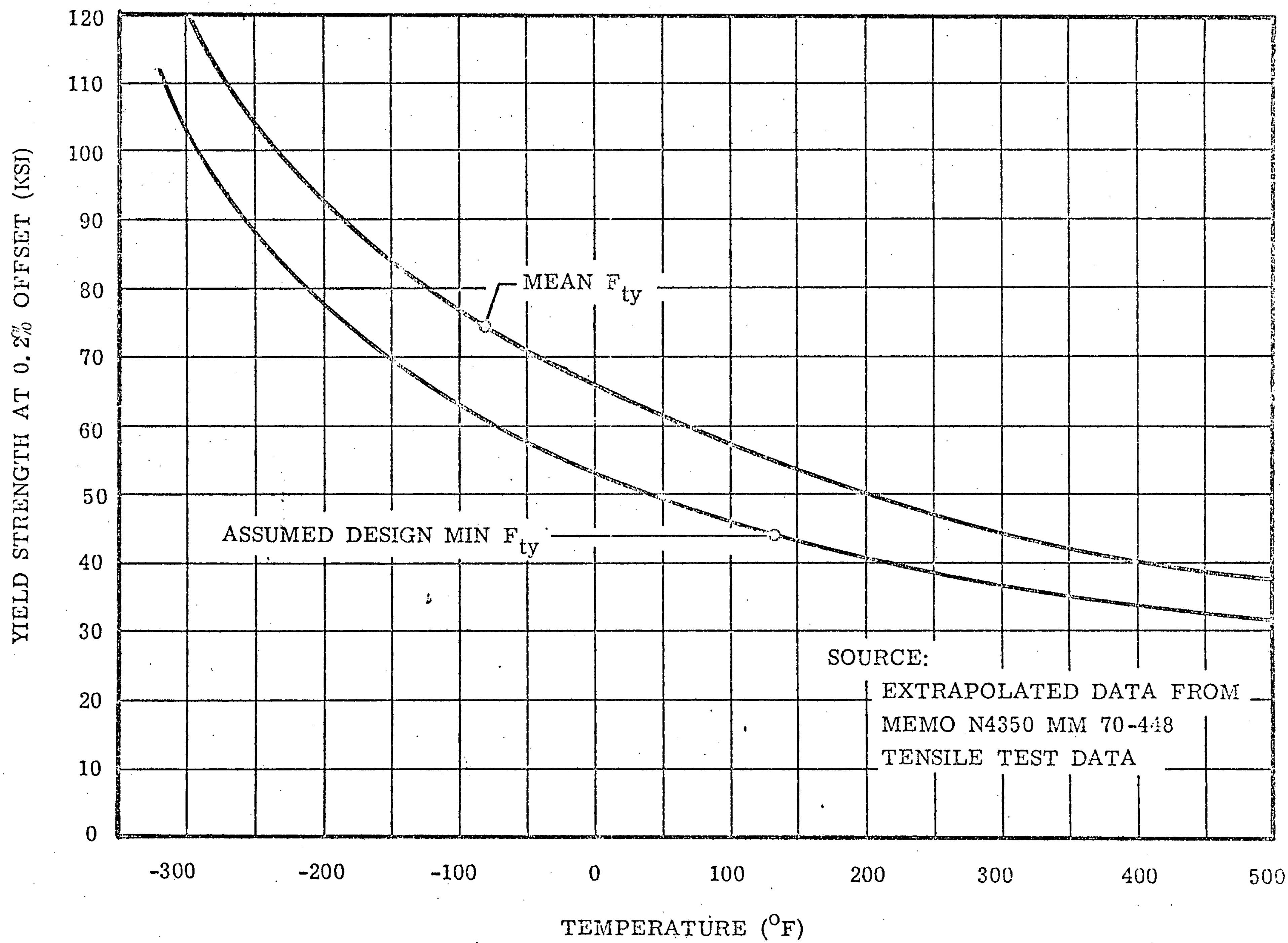
Forgings of Armco 22-13-5 have been ordered and fabricated for the purpose of materials testing to establish Class A data. No actual testing was accomplished, however, prior to contract cancellation.

D. THERMAL ANALYSIS

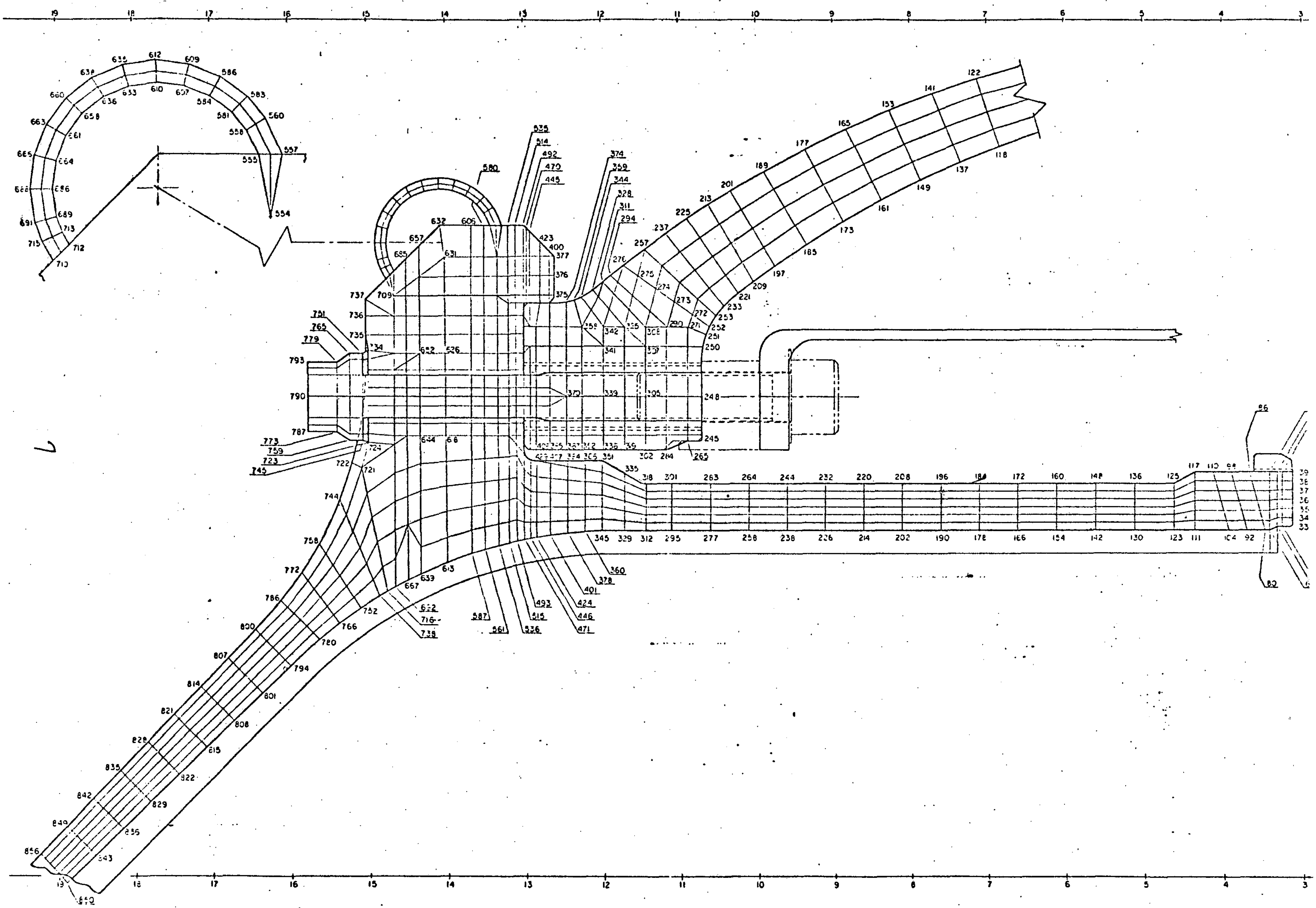
A thermal analysis was conducted to determine the specification extreme temperature of the flange area (Reference (c)). The temperatures used in this report however are based on a subsequent computer run (Run # JOE 428237,2,100). This computer run was a thermal sensitivity analysis in which nominal values of thermal conductivity, nuclear heating, and heat transfer coefficients were used, to determine nominal material temperatures. These parameters were then varried one at a time to determine the effect on material temperature. No report was written on this data because of personnel layoffs, however the data was used, and the computer run will be included with this data package.

The nominal temperatures were used to determine material yield strength, and the temperature variability (D_T) was used to help determine strength variability. This method provides a more accurate assessment of reliability. The previous method required use of the specification extreme temperature to determine material strength, however the analyist had no way of knowing how many standard deviations the spec extreme was from the mean temperature. The new method treats temperature the same as stress or material strength.

ARMCO 22-13-5 YIELD STRENGTH



NODE POINT LAYOUT FOR THERMAL SENSITIVITY ANALYSIS
COMPUTER RUN JOE 428237, 2, 100



AXIAL DISTANCE INCHES.

```
DR [illegible] MAIN,MAIN                                                    23 FEB 72    14:25:25.682
FORTRAN V: ISD VERSION 2.1
THIS COMPILATION WAS DONE ON 23 FEB 72 AT 14:25:25
```

JOE 428237, 2, 100

```
MAIN PROGRAM

STORAGE USED (BLOCK, NAME, LENGTH)

      0001    *CODE    000155
      0000    *DATA    014271
      0002    *BLANK   000000
```

JOE 428237, 2, 100

```
EXTERNAL REFERENCES (BLOCK, NAME)

      0003    NRDU$
      0004    NI02$
      0005    NWDU$
      0006    NI01$
      0007    NSTOP$


STORAGE ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

  0000    014152 1F        0001    000134 1000L     0001    000003 111G      0001    000006 114G      0001    000035 133G
  0001    000037 136G      0001    000065 154G      0001    000121 173G      0000    014156 2F        0001    000143 2000L
  0000    014225 3F        0000    014232 4F        0000    014241 5F        0001    000106 50L       0000 I 014144 J
  0000 I 014145 K          0000 I 014151 L          0000 I 014146 N          0000 I 014150 NL         0000 I 014147 NP
  0000 R 000000 R          0000 R 003370 T          0000 R 001574 Z
```

```
00100    C                                                                              C
00100    C******************************************************************************C
00100    C*                                                                            *C
00100    C*       PROGRAM TO CALCULATE SENSITIVITY COEFFICIENTS       J J WILLIAMS     *C
00100    C*                                                                            *C
00100    C******************************************************************************C
00100    C                                                                              C
00101          DIMENSION R(892),Z(892),T(892,5)
00103        1 FORMAT(I5,5X,2F10.4,20X,F10.2)
00104        2 FORMAT('1'/19X,'NERVA NOZZLE/PRESSURE VESSEL JOINT  -  NOMINAL TEM
00104         1PERATURES AND SENSITIVITY FACTORS *D*  PAGE',I3///
00104         2 ' NODE   LENGTH    RADIUS   NOMINAL TEMP      SF-1     SF-2    SF-
00104         33    SF-4'
00104         4 / 9X,'(IN)        (IN)        (DEG-R)'/)
00105        3 FORMAT(1X,I4,2F10.4,F11.2,6X, 4F8.2)
00106        4 FORMAT(/'  INPUT ERROR - JOB TERMINATED')
00107        5 FORMAT(/'  INPUT NODE NUMBER ERROR AT NODE',I4,' JOB TERMINATED')
00107    C
00110          DO 20 J=1,5
00113          DO 10 K=1,892
00116          READ(5,1,END=1000,ERR=1000) N,R(K),Z(K),T(K,J)
00124          IF(N.NE.K) GO TO 2000
00126       10 CONTINUE
00130       20 CONTINUE
```

```
00130      C
00132            DO 40 J=2,5
00135            DO 30 K=1,892
00140            T(K,J) = T(K,J) - T(K,1)
00141            T(K,J) = AINT(10.*T(K,J))/10.
00142         30 CONTINUE
00144         40 CONTINUE
00144      C
00146            NP = 1
00147            WRITE(6,2) NP
00152            NL=1
00153            DO 60 J=1,892
00156            IF(NL.LE.45) GO TO 50
00160            NP=NP+1
00161            NL=1
00162            WRITE(6,2) NP
00165         50 NL=NL+1
00166            WRITE(6,3) J,Z(J),R(J),(T(J,L),L=1,5)
00177         60 CONTINUE
00201            STOP
00202       1000 WRITE(6,4)
00204            STOP
00205       2000 WRITE(6,5) J
00210            STOP
00211            END

      END OF UNIVAC 1108 FORTRAN V COMPILATION.     0 *DIAGNOSTIC* MESSAGE(S)
```

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NERVA NOZZLE/PRESSURE VESSEL JOINT --- NOMINAL TEMPERATURES AND SENSITIVITY FACTORS *D* PAGE 1

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1 10% increase in AAMCO K	SF-2 +10% ALK	SF-3 +10% NUC HEAT	SF-4 +10% he
1	-16.0000	27.1600	387.64	.00	.00	17.90	-16.30
2	-16.0000	27.4400	399.02	.00	-1.00	18.70	-16.00
3	-16.0000	27.7200	405.74	.00	-1.60	19.30	-15.90
4	-16.0000	28.0000	407.95	.00	-1.80	19.50	-15.90
5	-14.0000	27.1600	387.64	.00	.00	17.90	-16.30
6	-14.0000	27.4400	399.02	.00	-1.00	18.70	-16.00
7	-14.0000	27.7200	405.74	.00	-1.60	19.30	-15.90
8	-14.0000	28.0000	407.95	.00	-1.80	19.50	-15.90
9	-12.0000	27.1600	387.63	.00	.00	17.90	-16.30
10	-12.0000	27.4400	399.01	.00	-1.00	18.70	-16.00
11	-12.0000	27.7200	405.73	.00	-1.60	19.30	-15.90
12	-12.0000	28.0000	407.95	.00	-1.80	19.50	-15.90
13	-10.0000	27.1600	387.62	.00	.00	17.90	-16.30
14	-10.0000	27.4400	399.00	.00	-1.00	18.70	-16.00
15	-10.0000	27.7200	405.72	.00	-1.60	19.30	-15.90
16	-10.0000	28.0000	407.94	.00	-1.80	19.50	-15.90
17	-8.0000	27.1600	387.60	.00	.00	17.80	-16.30
18	-8.0000	27.4400	398.97	.00	-1.00	18.70	-16.00
19	-8.0000	27.7200	405.69	.00	-1.60	19.30	-15.90
20	-8.0000	28.0000	407.91	.00	-1.80	19.50	-15.80
21	-6.0000	27.1600	387.52	.00	.00	17.80	-16.20
22	-6.0000	27.4400	398.89	.00	-1.00	18.70	-16.00
23	-6.0000	27.7200	405.61	.00	-1.60	19.30	-15.90
24	-6.0000	28.0000	407.82	.00	-1.80	19.40	-15.80
25	-4.0000	27.1600	387.29	.00	.00	17.80	-16.20
26	-4.0000	27.4400	398.65	.00	-1.10	18.70	-15.90
27	-4.0000	27.7200	405.37	.00	-1.70	19.20	-15.80
28	-4.0000	28.0000	407.58	.00	-1.90	19.40	-15.80
29	-2.0000	27.1600	386.64	.00	-.10	17.70	-16.00
30	-2.0000	27.4400	397.98	.00	-1.20	18.60	-15.80
31	-2.0000	27.7200	404.66	.00	-1.70	19.10	-15.70
32	-2.0000	28.0000	406.88	.00	-2.00	19.30	-15.60
33	3.1170	21.4750	694.52	-32.10	.00	41.00	-6.40
34	3.1170	21.5920	708.96	-33.10	.00	42.10	-6.50
35	3.1170	21.7060	742.32	-35.30	.00	44.70	-6.70
36	3.1170	21.8250	778.24	-37.70	.00	47.50	-7.00
37	3.1170	21.9410	806.40	-39.40	.00	49.60	-7.40
38	3.1170	22.0580	824.02	-40.50	.00	51.00	-7.60
39	3.1170	22.1750	829.95	-40.90	.00	51.40	-7.60
40	.0000	27.1600	384.72	.00	-.30	17.50	-15.70
41	.0000	27.4400	395.99	.00	-1.30	18.40	-15.50
42	.0000	27.7200	402.75	.00	-1.90	18.90	-15.30
43	.0000	28.0000	404.88	.00	-2.10	19.10	-15.30
44	3.2430	21.4750	653.73	-29.10	.00	37.80	-6.30
45	3.2430	21.5920	679.07	-31.00	.00	39.80	-6.40

NERVA NOZZLE/PRESSURE VESSEL JOINT - NOMINAL TEMPERATURES AND SENSITIVITY FACTORS *D* PAGE 2

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
46	3.2430	21.7080	724.87	-34.10	.00	43.40	-6.70
47	3.2430	21.8250	765.90	-36.80	.00	46.60	-7.10
48	3.2430	21.9420	796.03	-38.60	.00	48.90	-7.50
49	3.2430	22.0580	814.07	-39.70	.00	50.30	-7.70
50	3.2430	22.1750	820.24	-40.10	.00	50.70	-7.80
51	1.1500	27.1600	380.93	.00	-.30	17.10	-15.40
52	1.1500	27.3700	389.66	.00	-1.10	17.90	-15.20
53	1.1500	27.5800	395.77	.00	-1.70	19.30	-15.00
54	1.1500	27.7900	399.28	.00	-2.00	18.50	-15.00
55	1.1500	28.0000	400.53	.00	-2.10	18.60	-14.90
56	3.3100	21.4850	579.72	-23.60	.00	31.90	-6.30
57	3.3100	21.6000	646.85	-28.70	.00	37.40	-6.40
58	3.3100	21.7150	706.69	-32.80	.00	42.10	-6.80
59	3.3100	21.8300	751.73	-35.70	.00	45.60	-7.20
60	3.3100	21.9450	782.63	-37.60	.00	48.00	-7.70
61	3.3100	22.0600	800.62	-38.60	.00	49.40	-8.00
62	3.3100	22.1750	807.26	-39.00	.00	49.80	-8.00
63	2.3000	27.1600	375.85	.00	-.40	16.60	-14.90
64	2.3000	27.3700	384.24	.00	-1.20	17.20	-14.70
65	2.3000	27.5800	390.01	.00	-1.70	17.70	-14.60
66	2.3000	27.7900	393.39	.00	-2.00	18.00	-14.50
67	2.3000	28.0000	394.49	.00	-2.10	18.00	-14.50
68	3.4000	21.4260	290.39	-.70	.00	9.00	-7.50
69	3.4000	21.5510	542.35	-21.20	.00	29.10	-6.00
70	3.4000	21.6760	646.28	-28.60	.00	37.50	-6.60
71	3.4000	21.8000	710.76	-32.80	.00	42.50	-7.20
72	3.4000	21.9250	750.70	-35.10	.00	45.60	-7.90
73	3.4000	22.0500	771.78	-36.20	.00	47.30	-8.50
74	3.4000	22.1750	782.34	-37.00	.00	48.10	-8.40
75	3.4630	27.1030	367.12	.00	-.30	15.80	-14.30
76	3.4770	27.3150	375.66	.00	-1.10	16.40	-14.20
77	3.4920	27.5260	381.29	.00	-1.70	16.90	-14.00
78	3.5060	27.7380	384.50	.00	-1.90	17.10	-14.00
79	3.5200	27.9500	385.54	.00	-2.00	17.20	-13.90
80	3.4630	21.4200	248.05	.50	.00	5.00	-5.00
81	3.4970	21.5460	467.96	-15.80	.00	22.90	-5.60
82	3.5310	21.6720	577.78	-23.70	.00	32.30	-6.50
83	3.5650	21.7970	636.97	-27.30	.00	37.00	-7.60
84	3.5990	21.9230	661.03	-28.00	.00	39.10	-9.00
85	3.6330	22.0490	651.17	-25.80	.00	38.60	-11.10
86	3.6670	22.1750	601.08	-19.70	.00	35.30	-14.60
87	4.6070	26.9500	357.40	.00	-.40	14.80	-13.50
88	4.6470	27.1630	366.15	.00	-1.20	15.50	-13.30
89	4.6870	27.3770	371.99	.00	-1.70	16.00	-13.20
90	4.7270	27.5900	375.26	.00	-2.00	16.20	-13.10

NERVA NOZZLE/PRESSURE VESSEL JOINT — NOMINAL TEMPERATURES AND SENSITIVITY FACTORS *D* PAGE 3

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	°F	SF-1 ARMCO K	SF-2 AL K	SF-3 NUC HEAT	SF-4 R
91	4.7670	27.8030	376.27		.00	-2.10	16.30	-13.00
92	3.6870	21.4200	239.86		.40	.00	4.10	-4.10
93	3.7210	21.5460	397.12		-11.30	.00	17.50	-5.00
94	3.7550	21.6720	495.54		-17.60	.00	25.40	-6.30
95	3.7890	21.7970	548.70		-20.60	.00	30.20	-7.90
96	3.8220	21.9230	563.22		-20.20	.00	31.60	-9.80
97	3.8560	22.0490	538.01		-16.40	.00	29.90	-12.20
98	3.8900	22.1750	470.86		-8.80	.00	24.70	-15.60
99	5.7270	26.6930	345.44		.00	-.40	13.60	-12.20
100	5.7850	26.9110	354.53		.00	-1.20	14.30	-12.00
101	5.8420	27.1300	360.63		.00	-1.80	14.80	-11.90
102	5.9000	27.3490	364.04		.00	-2.10	15.10	-11.80
103	5.9580	27.5670	365.09		.00	-2.20	15.20	-11.80
104	3.9130	21.4200	221.75		.30	.00	2.30	-2.40
105	3.9480	21.5460	373.41		-10.10	.00	15.40	-4.20
106	3.9820	21.6720	461.48		-15.60	.00	23.00	-5.90
107	4.0160	21.7970	504.87		-17.30	.00	26.50	-7.40
108	4.0510	21.9230	508.48		-16.20	.00	27.00	-9.20
109	4.0860	22.0490	472.33		-11.90	.00	24.20	-11.30
110	4.1200	22.1750	392.14		-3.60	.00	18.10	-13.80
111	4.3470	21.4200	215.96		.20	.00	1.90	-1.90
112	4.3470	21.5460	358.40		-9.60	.00	14.20	-3.50
113	4.3470	21.6720	435.55		-14.20	.00	20.90	-5.10
114	4.3470	21.7970	468.62		-15.30	.00	23.50	-6.60
115	4.3470	21.9230	462.70		-13.40	.00	23.10	-8.20
116	4.3470	22.0490	419.62		-8.60	.00	19.90	-9.90
117	4.3470	22.1750	343.52		-1.10	.00	13.50	-11.80
118	6.8130	26.3470	330.85		.00	-.30	12.20	-10.70
119	6.8910	26.5690	340.20		.00	-1.20	13.00	-10.50
120	6.9700	26.7900	346.41		.00	-1.80	13.50	-10.40
121	7.0490	27.0120	349.89		.00	-2.10	13.70	-10.40
122	7.1270	27.2330	350.92		.00	-2.20	13.80	-10.30
123	4.6130	21.4200	213.53	-247	.20	.00	1.80	-1.80
124	4.6130	21.5200	323.13	-137	-7.60	.00	11.60	-3.10
125	4.6130	21.6200	389.22	-71	-11.30	.00	16.70	-4.10
126	4.6130	21.7200	423.52	-37	-12.90	.00	19.80	-5.40
127	4.6130	21.8200	428.79	-32	-12.10	.00	20.30	-6.70
128	4.6130	21.9200	403.90	-57	-8.70	.00	18.20	-8.20
129	4.6130	22.0200	344.13	-116	-2.30	.00	13.50	-10.60
130	5.1130	21.4200	211.20		.20	.00	1.70	-1.70
131	5.1130	21.5200	312.70		-7.00	.00	10.70	-2.80
132	5.1130	21.6200	372.71		-10.40	.00	15.30	-3.70
133	5.1130	21.7200	401.58		-11.60	.00	17.80	-4.80
134	5.1130	21.8200	403.24		-10.70	.00	17.90	-5.90
135	5.1130	21.9200	377.99		-7.50	.00	15.70	-7.10

Core Support on steel (nodes 111–117)

Core Support off steel (nodes 123–129)

D_T = 3° FOR K
13 FOR NUC heat
6 for R

$D_T = 22°$

USED FOR ANALYSIS OF CORE SUPPORT 4/19/72 (nodes 123–129)

R.B. Ackerman

Core Support

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
136	5.1130	22.0200	323.44	-1.90	.00	11.50	-9.00
137	7.3380	26.1400	321.44	.00	-.20	11.30	-9.90
138	7.4280	26.3630	331.45	.00	-1.10	12.10	-9.80
139	7.5190	26.5870	338.07	.00	-1.70	12.60	-9.70
140	7.6090	26.8100	341.71	.00	-2.00	12.90	-9.60
141	7.7000	27.0330	342.78	.00	-2.10	13.00	-9.60
142	5.6130	21.4200	209.21	.20	.00	1.60	-1.70
143	5.6130	21.5200	308.48	-6.90	.00	10.50	-2.60
144	5.6130	21.6200	367.33	-10.30	.00	14.90	-3.50
145	5.6130	21.7200	395.59	-11.40	.00	17.30	-4.50
146	5.6130	21.8200	397.37	-10.50	.00	17.40	-5.50
147	5.6130	21.9200	372.93	-7.50	.00	15.20	-6.70
148	5.6130	22.0200	319.16	-1.90	.00	11.10	-8.60
149	7.8570	25.9130	311.60	.00	.00	10.30	-9.10
150	7.9590	26.1390	321.91	.00	-1.00	11.20	-9.00
151	8.0600	26.3650	328.79	.00	-1.60	11.70	-9.00
152	8.1610	26.5910	332.62	.00	-1.90	12.10	-8.90
153	8.2630	26.8170	333.76	.00	-2.00	12.10	-8.90
154	6.1130	21.4200	207.28	.20	.00	1.60	-1.60
155	6.1130	21.5200	305.42	-6.80	.00	10.30	-2.60
156	6.1130	21.6200	363.70	-10.20	.00	14.70	-3.40
157	6.1130	21.7200	391.72	-11.30	.00	17.00	-4.30
158	6.1130	21.8200	393.60	-10.40	.00	17.10	-5.40
159	6.1130	21.9200	369.65	-7.40	.00	15.00	-6.60
160	6.1130	22.0200	316.79	-1.90	.00	10.90	-8.40
161	8.3670	25.6530	299.68	.00	.20	9.20	-8.40
162	8.4800	25.8820	311.12	.00	-.70	10.10	-8.30
163	8.5940	26.1100	318.75	.00	-1.40	10.80	-8.20
164	8.7070	26.3390	323.03	.00	-1.80	11.10	-8.20
165	8.8200	26.5670	324.28	.00	-1.90	11.20	-8.10
166	6.6130	21.4200	205.21	.20	.00	1.60	-1.60
167	6.6130	21.5200	302.36	-6.70	.00	10.10	-2.50
168	6.6130	21.6200	360.17	-10.10	.00	14.50	-3.40
169	6.6130	21.7200	388.04	-11.10	.00	16.70	-4.20
170	6.6130	21.8200	390.09	-10.20	.00	16.80	-5.30
171	6.6130	21.9200	366.64	-7.30	.00	14.80	-6.50
172	6.6130	22.0200	314.63	-1.90	.00	10.70	-8.30
173	8.8630	25.4030	288.97	.00	.40	8.10	-7.70
174	8.9890	25.6340	301.99	.00	-.60	9.20	-7.60
175	9.1150	25.8650	310.47	.00	-1.30	10.00	-7.50
176	9.2410	26.0970	315.14	.00	-1.70	10.40	-7.50
177	9.3670	26.3280	316.49	.00	-1.80	10.50	-7.50
178	7.1130	21.4200	203.13	.10	.00	1.60	-1.60
179	7.1130	21.5200	299.30	-6.70	.00	10.00	-2.50
180	7.1130	21.6200	356.65	-10.00	.00	14.40	-3.30

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
181	7.1130	21.7200	384.36	-11.00	.00	16.50	-4.20
182	7.1130	21.8200	386.59	-10.10	.00	16.60	-5.20
183	7.1130	21.9200	363.62	-7.30	.00	14.60	-6.40
184	7.1130	22.0200	312.47	-1.90	.00	10.60	-8.10
185	9.3500	25.1070	279.36	.00	.60	7.20	-6.90
186	9.4880	25.3400	293.74	.00	-.50	8.40	-6.90
187	9.6270	25.5730	303.23	-.10	-1.20	9.20	-6.90
188	9.7650	25.8070	308.52	-.10	-1.70	9.70	-6.90
189	9.9030	26.0400	310.17	-.10	-1.80	9.80	-6.90
190	7.6130	21.4200	201.04	.20	.00	1.50	-1.60
191	7.6130	21.5200	296.21	-6.60	.00	9.90	-2.50
192	7.6130	21.6200	353.09	-9.90	.00	14.20	-3.30
193	7.6130	21.7200	380.70	-10.90	.00	16.20	-4.10
194	7.6130	21.8200	383.06	-10.00	.00	16.30	-5.10
195	7.6130	21.9200	360.59	-7.20	.00	14.40	-6.30
196	7.6130	22.0200	310.32	-1.90	.00	10.40	-7.90
197	9.7570	24.8100	271.52	-.10	.80	6.40	-6.40
198	9.9000	25.0510	288.03	-.10	-.40	7.90	-6.40
199	10.0430	25.2920	299.01	-.10	-1.20	8.80	-6.50
200	10.1850	25.5320	305.13	-.10	-1.70	9.30	-6.50
201	10.3280	25.7730	307.11	-.10	-1.80	9.50	-6.50
202	8.1130	21.4200	198.90	.20	.00	1.50	-1.60
203	8.1130	21.5200	293.08	-6.50	.00	9.80	-2.40
204	8.1130	21.6200	349.51	-9.80	.00	14.00	-3.20
205	8.1130	21.7200	377.01	-10.80	.00	15.90	-4.00
206	8.1130	21.8200	379.54	-9.90	.00	16.00	-5.00
207	8.1130	21.9200	357.54	-7.10	.00	14.20	-6.20
208	8.1130	22.0200	308.16	-1.90	.00	10.20	-7.80
209	10.0400	24.6170	268.63	-.10	.90	6.10	-6.20
210	10.1830	24.8610	287.01	-.10	-.50	7.70	-6.20
211	10.3260	25.1050	298.64	-.20	-1.30	8.70	-6.20
212	10.4700	25.3490	305.01	-.20	-1.80	9.30	-6.20
213	10.6130	25.5930	306.98	-.20	-2.00	9.50	-6.30
214	8.6130	21.4200	196.78	.20	.00	1.50	-1.60
215	8.6130	21.5200	289.97	-6.40	.00	9.60	-2.40
216	8.6130	21.6200	345.91	-9.70	.00	13.90	-3.20
217	8.6130	21.7200	373.30	-10.60	.00	15.70	-4.00
218	8.6130	21.8200	376.01	-9.80	.00	15.90	-4.90
219	8.6130	21.9200	354.50	-7.10	.00	14.00	-6.00
220	8.6130	22.0200	306.01	-1.90	.00	10.10	-7.60
221	10.2330	24.4670	268.40	-.10	.80	6.10	-6.10
222	10.3980	24.7040	287.88	-.20	-.60	7.80	-6.10
223	10.5630	24.9400	299.98	-.20	-1.50	8.80	-6.10
224	10.7280	25.1770	306.55	-.20	-2.00	9.40	-6.10
225	10.8930	25.4130	308.60	-.20	-2.20	9.60	-6.10

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
226	9.1130	21.4200	194.67	.20	.00	1.50	-1.50
227	9.1130	21.5200	286.87	-6.30	.00	9.50	-2.30
228	9.1130	21.6200	342.32	-9.50	.00	13.70	-3.10
229	9.1130	21.7200	369.60	-10.50	.00	15.50	-3.90
230	9.1130	21.8200	372.50	-9.70	.00	15.60	-4.80
231	9.1130	21.9200	351.49	-7.00	.00	13.80	-5.90
232	9.1130	22.0200	303.89	-1.90	.00	9.90	-7.50
233	10.4180	24.3070	270.31	-.20	.70	6.30	-6.10
234	10.6060	24.5360	290.42	-.20	-.80	8.00	-6.00
235	10.7940	24.7650	302.62	-.30	-1.80	9.10	-6.00
236	10.9820	24.9940	309.60	-.30	-2.30	9.70	-6.00
237	11.1700	25.2230	311.83	-.30	-2.40	9.90	-6.00
238	9.6130	21.4200	192.64	.20	.00	1.50	-1.50
239	9.6130	21.5200	284.06	-6.20	.00	9.40	-2.30
240	9.6130	21.6200	339.12	-9.40	.00	13.60	-3.10
241	9.6130	21.7200	366.35	-10.30	.00	15.30	-3.90
242	9.6130	21.8200	369.43	-9.50	.00	15.40	-4.80
243	9.6130	21.9200	348.88	-6.90	.00	13.60	-5.90
244	9.6130	22.0200	302.25	-1.80	.00	9.70	-7.40
245	10.7070	22.5600	264.33	-.30	1.10	5.70	-5.90
246	10.7070	22.6430	264.87	-.30	1.10	5.70	-5.90
247	10.7070	22.8200	265.21	-.30	1.00	5.80	-5.90
248	10.7070	23.1330	266.18	-.30	1.00	5.90	-5.90
249	10.7070	23.4470	268.16	-.30	.90	6.00	-5.90
250	10.7070	23.7900	272.33	-.30	.60	6.40	-6.00
251	10.6530	23.9370	272.33	-.30	.60	6.40	-6.00
252	10.6070	24.0380	272.07	-.20	.60	6.40	-6.10
253	10.5230	24.1800	271.57	-.20	.60	6.40	-6.10
254	10.7520	24.3910	292.86	-.30	-1.00	8.20	-6.00
255	10.9820	24.6020	306.09	-.40	-2.00	9.30	-6.00
256	11.2110	24.8120	313.55	-.40	-2.50	10.00	-5.90
257	11.4400	25.0230	316.54	-.40	-2.80	10.20	-5.90
258	10.1130	21.4200	190.99	.20	.00	1.50	-1.60
259	10.1160	21.5200	283.51	-6.20	.00	9.50	-2.50
260	10.1200	21.6200	339.62	-9.40	.00	13.30	-3.30
261	10.1230	21.7200	357.73	-10.40	.00	15.60	-4.10
262	10.1260	21.8200	371.57	-9.50	.00	15.70	-5.00
263	10.1300	21.9200	350.90	-6.90	.00	13.90	-6.10
264	10.1330	22.0200	303.24	-1.80	.00	10.00	-7.50
265	10.8930	22.5600	279.42	-.40	.00	7.10	-6.00
266	10.8930	22.6430	278.96	-.40	.10	7.00	-6.00
267	10.8930	22.8200	278.91	-.40	.00	7.00	-5.90
268	10.8930	23.1330	280.11	-.40	.00	7.10	-5.90
269	10.8930	23.4470	282.40	-.40	-.10	7.30	-5.90
270	10.8930	23.7900	286.64	-.40	-.50	7.70	-6.00

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
271	10.8930	24.0380	291.55	-.40	-.90	8.10	-6.00
272	10.8270	24.1930	291.44	-.30	-.80	8.10	-6.00
273	11.0620	24.3590	305.40	-.40	-1.00	9.30	-5.90
274	11.2980	24.5240	314.68	-.50	-2.60	10.10	-5.90
275	11.5330	24.6900	320.17	-.50	-3.00	10.50	-5.90
276	11.7170	24.8200	322.27	-.60	-3.10	10.70	-5.90
277	10.6130	21.4200	190.21	.20	.00	1.60	-1.70
278	10.6130	21.5200	290.32	-6.60	.00	10.40	-2.90
279	10.6130	21.6200	353.20	-10.20	.00	15.10	-3.90
280	10.6130	21.7200	349.11	-11.50	.00	17.70	-4.90
281	10.6130	21.8200	399.52	-11.20	.00	19.60	-6.10
282	10.6130	21.9200	387.90	-9.00	.00	17.50	-7.50
283	10.6130	22.0200	351.49	-4.60	.00	14.50	-9.40
284	11.1620	22.4500	294.05	-.50	-.80	8.30	-6.20
285	11.1620	22.6430	294.11	-.50	-.90	8.30	-6.10
286	11.1620	22.8200	294.70	-.50	-1.00	8.40	-6.00
287	11.1620	23.1330	296.40	-.50	-1.10	8.50	-6.00
288	11.1620	23.4470	298.84	-.50	-1.30	8.70	-5.90
289	11.1620	23.7900	302.35	-.50	-1.60	9.00	-5.90
290	11.1620	24.0380	305.35	-.50	-1.90	9.30	-5.90
291	11.3700	24.2290	315.06	-.50	-2.60	10.10	-5.90
292	11.5770	24.4190	321.65	-.60	-3.00	10.70	-5.90
293	11.7850	24.6100	325.29	-.70	-3.30	11.00	-5.90
294	11.8830	24.6900	326.04	-.70	-3.30	11.00	-5.90
295	11.1130	21.4200	189.95	.20	.00	1.80	-1.90
296	11.1130	21.5200	300.63	-7.50	.00	11.50	-3.10
297	11.1130	21.6200	372.85	-11.70	.00	16.90	-4.10
298	11.1130	21.7200	418.80	-14.20	.00	20.80	-5.30
299	11.1130	21.8200	444.79	-15.20	.00	22.90	-6.50
300	11.1130	21.9200	453.28	-14.80	.00	23.60	-7.80
301	11.1130	22.0200	446.95	-13.40	.00	23.20	-9.00
302	11.4370	22.4500	303.32	-.50	-1.40	9.20	-6.20
303	11.4370	22.6430	305.29	-.60	-1.60	9.30	-6.20
304	11.4370	22.8200	306.71	-.50	-1.70	9.40	-6.10
305	11.4370	23.1330	309.12	-.60	-2.00	9.60	-6.00
306	11.4370	23.4470	311.59	-.60	-2.20	9.80	-6.00
307	11.4370	23.7900	314.44	-.60	-2.50	10.10	-5.90
308	11.4370	24.0380	316.04	-.60	-2.60	10.20	-5.90
309	11.6380	24.2440	323.08	-.70	-3.10	10.80	-5.90
310	11.8400	24.4500	327.40	-.70	-3.40	11.20	-5.90
311	11.9800	24.6130	328.57	-.70	-3.50	11.20	-5.90
312	11.4670	21.4200	189.13	.20	.00	1.90	-2.00
313	11.4670	21.5200	301.51	-7.60	.00	11.70	-3.20
314	11.4670	21.6200	374.78	-11.70	.00	17.20	-4.20
315	11.4670	21.7200	421.40	-14.20	.00	21.20	-5.40

NERVA NOZZLE/PRESSURE VESSEL JOINT — NOMINAL TEMPERATURES AND SENSITIVITY FACTORS *D* PAGE 8

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
316	11.4670	21.6200	446.82	-15.00	.00	23.20	-6.70
317	11.4670	21.9200	451.92	-14.20	.00	23.60	-8.10
318	11.4670	22.0200	435.78	-11.50	.00	22.40	-9.80
319	11.7100	22.4500	310.91	-.60	-1.70	9.90	-6.40
320	11.7100	22.6430	313.49	-.60	-2.00	10.10	-6.30
321	11.7100	22.8200	315.56	-.70	-2.20	10.20	-6.20
322	11.7100	23.1330	318.66	-.70	-2.60	10.50	-6.10
323	11.7100	23.4470	321.24	-.70	-2.80	10.70	-6.00
324	11.7100	23.7900	323.43	-.70	-3.00	10.80	-6.00
325	11.7100	24.0380	324.62	-.70	-3.20	10.90	-5.90
326	11.9100	24.2600	329.57	-.90	-3.50	11.30	-5.90
327	12.0400	24.4170	331.53	-.80	-3.60	11.50	-5.90
328	12.1100	24.5100	331.83	-.90	-3.60	11.50	-5.90
329	11.7170	21.4200	188.17	.20	.00	1.90	-2.00
330	11.7170	21.5420	320.33	-8.80	.00	13.40	-3.30
331	11.7170	21.6640	398.70	-13.00	.00	19.20	-4.50
332	11.7170	21.7860	443.76	-15.20	.00	23.00	-5.90
333	11.7170	21.9090	462.08	-15.00	.00	24.30	-7.30
334	11.7170	22.0310	456.54	-13.00	.00	24.00	-8.80
335	11.7170	22.1530	429.78	-9.20	.00	22.00	-10.40
336	11.9770	22.4500	315.76	-.70	-1.90	10.30	-6.50
337	11.9770	22.6430	319.21	-.70	-2.20	10.60	-6.40
338	11.9770	22.8200	321.82	-.70	-2.50	10.80	-6.30
339	11.9770	23.1330	325.53	-.80	-2.90	11.10	-6.20
340	11.9770	23.4470	328.33	-.80	-3.20	11.30	-6.10
341	11.9770	23.7900	330.54	-.90	-3.40	11.40	-6.00
342	11.9770	24.0380	331.18	-.90	-3.50	11.50	-6.00
343	12.1370	24.2500	334.50	-1.00	-3.70	11.70	-6.00
344	12.2500	24.4200	335.80	-1.00	-3.70	11.90	-6.00
345	12.0000	21.4100	186.86	.20	.00	1.90	-1.90
346	12.0000	21.5610	340.63	-10.10	.00	14.80	-3.50
347	12.0000	21.7120	424.48	-14.50	.00	21.60	-4.90
348	12.0000	21.8630	466.15	-16.00	.00	24.70	-6.40
349	12.0000	22.0150	473.79	-14.80	.00	25.20	-7.90
350	12.0000	22.1660	452.61	-11.40	.00	23.60	-9.60
351	12.0000	22.3170	408.12	-6.00	.00	20.00	-11.20
352	12.2500	22.4500	319.02	-.80	-1.90	10.60	-6.70
353	12.2500	22.6430	323.12	-.80	-2.30	10.90	-6.60
354	12.2500	22.8200	326.18	-.90	-2.70	11.20	-6.50
355	12.2500	23.1330	330.43	-.90	-3.10	11.50	-6.30
356	12.2500	23.4470	333.52	-1.00	-3.40	11.70	-6.20
357	12.2500	23.7900	335.91	-1.00	-3.60	11.90	-6.10
358	12.2500	24.0380	336.94	-1.10	-3.80	12.00	-6.00
359	12.3530	24.3830	338.59	-1.10	-3.80	12.10	-6.00
360	12.2170	21.4000	186.06	.20	.00	1.90	-1.90

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
361	12.2170	21.5530	342.25	-10.30	.00	15.00	-3.40
362	12.2170	21.7060	427.20	-14.80	.00	21.80	-4.80
363	12.2170	21.8590	470.31	-16.40	.00	25.00	-6.20
364	12.2170	22.0110	479.25	-15.30	.00	25.50	-7.60
365	12.2170	22.1640	458.13	-11.90	.00	24.00	-9.30
366	12.2170	22.3170	405.93	-5.70	.00	19.80	-11.30
367	12.4570	22.4500	320.77	-.80	-1.90	10.80	-6.80
368	12.4570	22.6430	324.99	-.90	-2.30	11.10	-6.70
369	12.4570	22.8200	328.27	-.90	-2.70	11.40	-6.60
370	12.4570	23.1330	332.90	-1.00	-3.10	11.70	-6.40
371	12.4570	23.4470	336.10	-1.10	-3.50	11.90	-6.20
372	12.4570	23.7900	338.91	-1.20	-3.70	12.10	-6.10
373	12.4570	24.0380	340.60	-1.30	-3.90	12.30	-6.00
374	12.4570	24.3570	341.22	-1.30	-3.90	12.30	-6.00
375	12.6130	24.4430	372.55	-4.50	-3.40	14.70	-5.50
376	12.6130	24.6950	398.05	-7.80	-2.50	16.90	-5.10
377	12.6130	24.9470	405.31	-9.10	-2.00	17.50	-4.90
378	12.4380	21.3780	184.82	.20	.00	1.80	-1.90
379	12.4380	21.5340	341.37	-10.30	.00	14.90	-3.30
380	12.4380	21.6910	427.97	-15.00	.00	21.90	-4.60
381	12.4380	21.8480	472.18	-16.60	.00	25.00	-6.00
382	12.4380	22.0040	481.38	-15.60	.00	25.60	-7.40
383	12.4380	22.1610	459.24	-12.10	.00	23.90	-9.20
384	12.4380	22.3170	406.04	-5.80	.00	19.70	-11.20
385	12.6700	22.4500	321.49	-.90	-1.80	10.80	-6.90
386	12.6700	22.6430	325.87	-.90	-2.20	11.20	-6.80
387	12.6700	22.8200	329.35	-1.00	-2.60	11.50	-6.70
388	12.6700	23.0170	332.69	-1.10	-2.90	11.70	-6.50
389	12.6700	23.1330	334.22	-1.10	-3.10	11.80	-6.50
390	12.6700	23.2530	335.66	-1.10	-3.20	11.90	-6.40
391	12.6700	23.4470	337.53	-1.20	-3.40	12.10	-6.30
392	12.6700	23.7900	340.73	-1.30	-3.70	12.30	-6.10
393	12.6700	24.0380	343.62	-1.50	-3.90	12.50	-6.00
394	12.6700	24.3400	347.06	-1.60	-4.10	12.80	-5.90
395	12.6750	24.3450	347.37	-1.60	-4.10	12.90	-5.90
396	12.6700	24.3500	347.46	-1.60	-4.10	12.80	-5.90
397	12.6700	24.4430	370.29	-4.30	-3.50	14.50	-5.50
398	12.6700	24.6950	397.99	-7.80	-2.50	16.80	-5.10
399	12.6700	24.9470	404.70	-9.00	-2.00	17.40	-4.90
400	12.6700	25.0070	403.71	-9.00	-1.90	17.30	-4.90
401	12.6700	21.3500	183.62	.20	.00	1.80	-1.80
402	12.6700	21.5110	341.19	-10.40	.00	14.90	-3.20
403	12.6700	21.6720	427.19	-15.00	.00	21.60	-4.50
404	12.6700	21.8330	471.22	-16.70	.00	24.80	-5.80
405	12.6700	21.9950	480.46	-15.70	.00	25.40	-7.20

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
406	12.6700	22.1560	457.84	-12.20	.00	23.70	-8.80
407	12.6700	22.3170	402.52	-5.70	.00	19.20	-10.90
408	12.8470	22.4500	320.68	-.90	-1.60	10.80	-7.00
409	12.8470	22.6430	325.74	-1.00	-2.10	11.20	-6.90
410	12.8470	22.8600	460.00	.00	.00	.00	.00
411	12.8470	23.0170	333.61	-1.10	-2.90	11.80	-6.60
412	12.8470	23.1330	460.00	.00	.00	.00	.00
413	12.8470	23.2530	336.25	-1.20	-3.20	12.00	-6.50
414	12.8470	23.4150	460.00	.00	.00	.00	.00
415	12.8470	23.7900	340.60	-1.40	-3.60	12.30	-6.20
416	12.8470	24.0380	345.62	-1.60	-3.90	12.70	-6.00
417	12.7970	24.3400	349.51	-1.90	-4.10	13.00	-5.90
418	12.8020	24.3450	349.64	-1.90	-4.10	13.00	-5.90
419	12.7970	24.3500	349.67	-1.90	-4.10	13.00	-5.90
420	12.7970	24.4430	367.82	-4.10	-3.50	14.30	-5.50
421	12.7970	24.6950	394.45	-7.60	-2.40	16.50	-5.00
422	12.7970	24.9470	400.67	-8.90	-1.80	17.00	-4.90
423	12.7970	25.1230	395.61	-8.70	-1.60	16.60	-4.80
424	12.8500	21.3200	181.58	.20	.00	1.70	-1.70
425	12.8500	21.5190	358.86	-11.30	.00	16.10	-3.30
426	12.8500	21.7190	445.09	-15.80	.00	22.80	-4.90
427	12.8500	21.9180	476.55	-16.20	.00	25.00	-6.40
428	12.8500	22.1180	462.23	-13.20	-.10	23.90	-8.10
429	12.8500	22.3170	402.98	-6.10	-.10	19.10	-10.40
430	12.9270	22.4500	319.94	-.90	-1.50	10.70	-7.10
431	12.9270	22.6430	325.39	-1.00	-2.00	11.20	-7.00
432	12.9270	22.8600	460.00	.00	.00	.00	.00
433	12.9270	23.0170	333.67	-1.10	-2.90	11.80	-6.60
434	12.9270	23.1330	460.00	.00	.00	.00	.00
435	12.9270	23.2530	336.32	-1.30	-3.10	12.00	-6.50
436	12.9270	23.4100	460.00	.00	.00	.00	.00
437	12.9270	23.7900	339.98	-1.40	-3.50	12.20	-6.20
438	12.9270	24.0380	346.74	-1.70	-4.00	12.70	-5.90
439	12.9270	24.3400	350.70	-2.10	-4.00	13.00	-5.90
440	12.9320	24.3450	350.98	-2.10	-4.00	13.00	-5.90
441	12.9270	24.3500	350.90	-2.10	-4.00	13.00	-5.90
442	12.9270	24.4430	365.20	-4.10	-3.30	14.10	-5.50
443	12.9270	24.6950	386.66	-7.20	-2.20	15.80	-5.00
444	12.9270	24.9470	391.96	-8.30	-1.60	16.30	-4.80
445	12.9270	25.2570	383.40	-8.10	-1.30	15.50	-4.80
446	12.9270	21.3100	175.50	.50	-.20	1.10	-1.20
447	12.9270	21.5110	357.87	-11.10	.00	15.90	-3.40
448	12.9270	21.7130	441.31	-15.50	.00	22.50	-5.00
449	12.9270	21.9140	472.17	-15.90	-.10	24.50	-6.40
450	12.9270	22.1160	459.38	-13.10	-.10	23.50	-7.90

NODE	LENGTH (IN)	RADIUS, (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
451	12.9270	22.3170	398.73	-6.10	-.20	18.50	-9.90
452	13.0000	22.6430	324.88	-1.00	-1.90	11.20	-7.10
453	13.0050	22.6380	324.86	-1.00	-1.90	11.20	-7.10
454	13.0000	22.8600	460.00	.00	.00	.00	.00
455	13.0000	23.0170	334.15	-1.20	-2.90	11.80	-6.70
456	13.0050	23.0120	334.04	-1.20	-2.80	11.80	-6.70
457	13.0000	23.1330	460.00	.00	.00	.00	.00
458	13.0000	23.2530	336.32	-1.30	-3.10	12.00	-6.50
459	13.0050	23.2480	336.26	-1.30	-3.10	12.00	-6.50
460	13.0000	23.4100	460.00	.00	.00	.00	.00
461	13.0000	23.6930	338.71	-1.50	-3.30	12.20	-6.30
462	13.0050	23.6880	338.62	-1.50	-3.30	12.10	-6.30
463	13.0000	24.1670	349.02	-2.00	-3.90	12.90	-5.90
464	13.0050	24.1620	349.06	-2.10	-3.90	12.90	-5.90
465	13.0000	24.3400	350.71	-2.10	-4.00	13.00	-5.90
466	12.9640	24.3500	351.92	-2.20	-4.00	13.10	-5.90
467	12.9640	24.4430	364.01	-4.10	-3.20	14.00	-5.50
468	12.9640	24.6950	383.61	-7.00	-2.10	15.50	-5.00
469	12.9640	24.9470	388.44	-8.10	-1.60	16.00	-4.80
470	12.9640	25.3000	379.59	-7.90	-1.20	15.20	-4.70
471	13.0100	21.2900	179.44	.20	.00	1.50	-1.60
472	13.0100	21.5100	359.35	-11.00	.00	15.90	-3.50
473	13.0100	21.7300	441.87	-15.20	.00	22.40	-5.20
474	13.0100	21.9500	466.65	-15.10	-.10	24.00	-6.70
475	13.0100	22.1700	444.03	-11.60	-.10	22.10	-8.20
476	13.0100	22.3900	376.00	-4.40	-.30	16.10	-9.50
477	13.0100	22.6430	324.84	-1.00	-1.90	11.20	-7.10
478	13.0100	22.7900	324.40	-1.10	-2.30	11.40	-6.90
479	13.0100	22.8600	460.00	.00	.00	.00	.00
480	13.0100	23.0170	334.21	-1.20	-2.80	11.90	-6.70
481	13.0100	23.1330	460.00	.00	.00	.00	.00
482	13.0100	23.2530	336.30	-1.30	-3.00	12.00	-6.50
483	13.0100	23.4100	460.00	.00	.00	.00	.00
484	13.0100	23.4600	337.46	-1.40	-3.20	12.10	-6.40
485	13.0100	23.6950	338.68	-1.50	-3.30	12.20	-6.30
486	13.0100	23.9530	350.56	-4.10	-2.20	13.00	-5.60
487	13.0100	24.1670	349.09	-2.10	-3.90	12.90	-5.90
488	13.0100	24.3500	350.87	-2.10	-4.00	13.00	-5.90
489	13.0100	24.4430	362.26	-4.20	-3.10	13.80	-5.50
490	13.0100	24.6950	379.21	-6.80	-2.00	15.20	-5.00
491	13.0100	24.9470	383.34	-7.80	-1.50	15.50	-4.80
492	13.0100	25.3330	375.24	-7.60	-1.10	14.80	-4.80
493	13.1000	21.2700	180.06	.20	.00	1.60	-1.70
494	13.1000	21.5450	379.33	-11.90	.00	17.40	-4.00
495	13.1000	21.8200	450.47	-14.80	.00	22.80	-6.00

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
496	13.1000	22.0950	450.20	-12.70	-.10	22.50	-7.60
497	13.1000	22.3700	393.97	-6.60	-.40	17.50	-8.60
498	13.1000	22.5070	366.64	-4.40	-.80	14.90	-8.00
499	13.1000	22.6450	342.10	-2.50	-1.30	12.70	-7.50
500	13.1000	22.7900	316.77	-.20	-1.60	10.60	-7.80
501	13.1000	22.8600	460.00	.00	.00	.00	.00
502	13.1000	23.0170	342.08	-2.40	-2.30	12.50	-6.70
503	13.1000	23.1330	460.00	.00	.00	.00	.00
504	13.1000	23.2530	342.23	-2.40	-2.50	12.40	-6.50
505	13.1000	23.4100	460.00	.00	.00	.00	.00
506	13.1000	23.4800	317.49	-.20	-2.20	10.60	-7.20
507	13.1000	23.6930	338.96	-2.40	-2.50	12.10	-6.20
508	13.1000	23.9330	347.59	-3.80	-2.20	12.70	-5.70
509	13.1000	24.1670	348.79	-3.10	-3.00	12.80	-5.70
SHEAR LIP -510	13.1000	24.3500	351.99 -109	-3.50	-3.00	13.10	-5.60
511	13.1000	24.4430	356.69	-4.30	-2.70	13.40	-5.40
512	13.1000	24.6950	368.54	-6.30	-1.80	14.30	-5.00
513	13.1000	24.9470	371.29	-7.10	-1.40	14.50	-4.80
514	13.1000	25.3330	365.11	-7.00	-1.00	14.00	-4.80
515	13.2100	21.2430	177.80	.30	.00	1.40	-1.60
516	13.2100	21.5230	362.99	-10.40	.00	15.90	-4.20
517	13.2100	21.8030	430.35	-13.00	.00	21.00	-6.20
518	13.2100	22.0830	433.68	-11.40	-.10	21.00	-7.60
519	13.2100	22.3630	393.64	-7.10	-.30	17.30	-8.10
520	13.2100	22.6430	346.04	-3.20	-.90	13.00	-7.70
521	13.2100	22.7900	311.81	-.20	-1.00	10.20	-8.10
522	13.2100	22.8600	460.00	.00	.00	.00	.00
523	13.2100	23.0170	343.69	-3.10	-1.70	12.60	-6.70
524	13.2100	23.1330	460.00	.00	.00	.00	.00
525	13.2100	23.2530	341.74	-3.00	-1.90	12.40	-6.50
526	13.2100	23.4100	460.00	.00	.00	.00	.00
527	13.2100	23.4800	304.69	.00	-1.50	9.50	-7.20
528	13.2100	23.6930	330.03	-2.40	-1.90	11.40	-6.10
529	13.2100	23.9330	338.02	-3.40	-1.90	12.00	-5.60
530	13.2100	24.1670	340.12	-3.40	-2.30	12.10	-5.50
531	13.2100	24.3500	342.47	-3.70	-2.20	12.30	-5.40
532	13.2100	24.4430	344.30	-4.00	-2.10	12.40	-5.30
533	13.2100	24.6950	351.21	-5.30	-1.50	12.90	-5.00
534	13.2100	24.9470	352.49	-6.00	-1.10	13.00	-4.90
535	13.2100	25.3330	345.74	-5.70	-.80	12.50	-5.00
536	13.3400	21.2100	175.13	.40	.00	1.10	-1.40
537	13.3400	21.4970	337.54	-7.90	.00	13.70	-4.80
538	13.3400	21.7830	396.46	-9.70	.00	17.80	-6.70
539	13.3400	22.0700	401.86	-8.60	-.10	18.00	-7.80
540	13.3400	22.3560	374.53	-5.80	-.30	15.50	-8.00

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
541	13.3400	22.6430	334.67	-2.70	-.60	12.10	-7.80
542	13.3400	22.7900	304.08	.00	-.60	9.50	-8.00
543	13.3400	22.8600	460.00	.00	.00	.00	.00
544	13.3400	23.0170	340.52	-3.40	-1.20	12.30	-6.70
545	13.3400	23.1330	460.00	.00	.00	.00	.00
546	13.3400	23.2530	336.78	-3.30	-1.30	12.00	-6.40
547	13.3400	23.4100	460.00	.00	.00	.00	.00
548	13.3400	23.4600	292.42	.20	-1.00	8.30	-6.90
549	13.3400	23.6930	311.17	-1.70	-1.30	9.90	-6.00
550	13.3400	23.9330	316.94	-2.40	-1.40	10.30	-5.60
551	13.3400	24.1670	318.24	-2.50	-1.50	10.40	-5.40
SL 552	13.3400	24.4430	320.58 -14°	-3.00	-1.40	10.60	-5.20
553	13.3400	24.6950	322.93	-3.60	-1.10	10.70	-5.10
554	13.3400	24.9470	323.51	-4.10	-.80	10.80	-4.90
555	13.4330	25.3330	295.72	-1.90	-.40	8.40	-5.30
556	13.3570	25.3330	313.46	-3.30	-.60	9.90	-5.30
557	13.2830	25.3330	328.11	-4.40	-.70	11.10	-5.20
558	13.5030	25.4830	302.27	-1.80	-.30	9.10	-6.30
559	13.4470	25.5210	304.31	-2.00	-.30	9.30	-6.10
560	13.3900	25.5600	303.66	-2.00	-.30	9.20	-6.10
561	13.5170	21.1630	174.35	.30	.00	1.00	-1.20
562	13.5170	21.4590	286.30	-2.40	.00	8.90	-5.90
563	13.5170	21.7550	323.16	-2.50	.00	11.80	-8.60
564	13.5170	22.0510	327.72	-1.70	.00	12.00	-9.50
565	13.5170	22.3470	313.21	-.70	-.10	10.60	-9.00
566	13.5170	22.6430	292.31	.30	-.20	8.50	-7.90
567	13.5170	22.7900	284.59	.60	-.30	7.70	-7.50
568	13.5170	22.8600	460.00	.00	.00	.00	.00
569	13.5170	23.0170	332.79	-3.50	-.70	11.70	-6.50
570	13.5170	23.1330	460.00	.00	.00	.00	.00
571	13.5170	23.2530	327.73	-3.40	-.70	11.20	-6.10
572	13.5170	23.4100	460.00	.00	.00	.00	.00
573	13.5170	23.4800	271.58	.70	-.50	6.40	-6.10
574	13.5170	23.6930	268.62	.70	-.50	6.10	-5.80
575	13.5170	23.9330	269.54	.50	-.60	6.10	-5.60
576	13.5170	24.1670	269.39	.40	-.60	6.10	-5.40
577	13.5170	24.4430	269.00	.30	-.60	6.00	-5.30
578	13.5170	24.6950	268.44	.10	-.50	6.00	-5.20
579	13.5170	24.9470	267.33	.00	-.30	5.90	-5.10
580	13.5170	25.3370	264.48	.20	-.20	5.60	-5.10
581	13.6000	25.6000	298.58	-1.20	-.20	8.80	-6.70
582	13.5540	25.6500	301.97	-1.60	-.20	9.10	-6.60
583	13.5080	25.7000	303.18	-1.70	-.20	9.20	-6.60
584	13.7500	25.7100	295.28	-.90	-.10	8.60	-6.90
585	13.7170	25.7710	298.56	-1.20	-.10	8.80	-6.80

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
586	13.6830	25.8330	299.61	-1.30	-.10	8.90	-6.80
587	13.6830	21.1130	173.87	.30	.00	1.00	-1.30
588	13.6830	21.4190	284.54	-2.30	.00	9.70	-5.90
589	13.6830	21.7250	313.28	-1.70	.00	10.90	-8.50
590	13.6830	22.0310	316.35	-1.00	.00	10.90	-9.20
591	13.6830	22.3370	305.27	-.30	.00	9.80	-8.70
592	13.6830	22.6430	287.03	.30	-.10	8.00	-7.60
593	13.6830	22.7900	279.74	.50	-.10	7.20	-7.10
594	13.6830	22.8600	460.00	.00	.00	.00	.00
595	13.6830	23.0170	324.66	-3.40	-.40	11.00	-6.30
596	13.6830	23.1330	460.00	.00	.00	.00	.00
597	13.6830	23.2530	318.91	-3.30	-.40	10.50	-5.30
598	13.6830	23.4100	460.00	.00	.00	.00	.00
599	13.6830	23.4800	265.20	.60	-.20	5.70	-5.60
600	13.6830	23.6930	260.36	.70	-.20	5.20	-5.30
601	13.6830	23.9330	259.36	.60	-.20	5.10	-5.10
602	13.6830	24.1670	258.02	.60	-.20	5.00	-4.90
603	13.6830	24.4430	256.02	.60	-.20	4.90	-4.70
SL, 604	13.6830	24.6950	253.89 - 207	.60	-.20	4.60	-4.60
605	13.6830	24.9470	251.56	.60	-.10	4.40	-4.50
606	13.6830	25.3330	247.35	.80	-.10	4.00	-4.30
607	13.9130	25.7770	291.45	-.60	-.10	8.20	-6.80
608	13.8960	25.8430	294.56	-.90	-.10	8.50	-6.80
609	13.8800	25.9100	295.55	-1.00	.00	8.60	-6.80
610	14.0900	25.7970	287.69	-.40	.00	7.80	-6.70
611	14.0940	25.8650	289.99	-.70	.00	8.10	-6.60
612	14.0970	25.9330	290.89	-.80	.00	8.10	-6.60
613	14.0000	20.9900	171.68	.30	.00	1.10	-1.30
614	14.0000	21.3210	325.95	-7.30	.00	12.90	-4.60
615	14.0000	21.6510	367.49	-7.40	.00	15.10	-6.70
616	14.0000	21.9820	370.92	-6.50	.00	15.00	-7.50
617	14.0000	22.3120	355.22	-5.30	.00	13.60	-7.30
618	14.0000	22.6430	318.48	-2.90	.00	10.60	-6.80
619	14.0000	22.7900	287.32	-.30	.00	7.90	-6.90
620	14.0000	22.8600	460.00	.00	.00	.00	.00
621	14.0000	23.0170	314.20	-3.30	-.10	10.10	-5.80
622	14.0000	23.1330	460.00	.00	.00	.00	.00
623	14.0000	23.2530	307.45	-3.20	-.10	9.50	-5.30
624	14.0000	23.4100	460.00	.00	.00	.00	.00
625	14.0000	23.4800	268.75	-.10	-.10	6.00	-5.30
626	14.0000	23.6950	280.50	-1.60	-.10	7.00	-4.60
627	14.0000	23.9330	281.14	-2.00	-.10	7.00	-4.30
628	14.0000	24.1670	278.30	-1.90	-.10	6.80	-4.10
629	14.0000	24.4430	273.60	-1.70	-.10	6.30	-3.90
630	14.0000	24.6950	268.38	-1.30	-.10	5.80	-3.80

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
SL - 631	14.0000	24.9470	264.75 -196	-1.10	-.10	5.50	-3.80
632	14.0830	25.3330	259.63	-.50	-.10	5.10	-4.00
633	14.2730	25.7670	282.41	-.30	.00	7.40	-6.40
634	14.2930	25.8330	285.23	-.50	.00	7.60	-6.40
635	14.3130	25.9000	286.13	-.60	.00	7.70	-6.40
636	14.4370	25.7000	277.86	-.20	.00	6.90	-6.10
637	14.4740	25.7580	280.45	-.40	.00	7.10	-6.10
638	14.5100	25.8170	281.28	-.50	.00	7.20	-6.00
639	14.3330	20.8500	171.49	.40	.00	1.00	-1.20
640	14.3330	21.2090	272.11	-1.60	.00	7.70	-5.60
641	14.3330	21.5670	306.32	-1.10	.00	10.20	-8.40
642	14.3330	21.9260	306.47	-.60	.00	10.00	-8.70
643	14.3330	22.2840	293.22	-.10	.00	8.60	-7.80
644	14.3330	22.6430	273.15	.20	.00	6.60	-6.30
645	14.3330	22.7900	265.30	.40	.00	5.80	-5.70
646	14.3330	22.8600	460.00	.00	.00	.00	.00
647	14.3330	23.0170	298.17	-2.70	.00	8.60	-5.10
648	14.3330	23.1330	460.00	.00	.00	.00	.00
649	14.3330	23.2530	292.11	-2.70	.00	8.00	-4.60
650	14.3330	23.4100	460.00	.00	.00	.00	.00
651	14.3330	23.4800	250.73	.20	.00	4.30	-4.20
652	14.3330	23.6950	247.62	.20	.00	3.90	-3.90
653	14.3330	23.9330	246.56	.20	.00	3.90	-3.70
654	14.3330	24.1670	244.68	.20	.00	3.60	-3.50
655	14.3330	24.4430	241.57	.20	.00	3.30	-3.30
656	14.3330	24.6950	239.38	.30	.00	3.10	-3.10
SL. - 657	14.3330	25.0700	237.95 -223	.50	.00	3.00	-3.20
658	14.5800	25.5900	272.97	-.10	.00	6.40	-5.70
659	14.6300	25.6360	275.39	-.40	.00	6.70	-5.70
660	14.6800	25.6830	276.15	-.40	.00	6.70	-5.70
661	14.6870	25.4470	268.04	-.10	.00	6.00	-5.30
662	14.7470	25.4780	270.26	-.30	.00	6.20	-5.30
663	14.8070	25.5100	270.96	-.40	.00	6.20	-5.30
664	14.7530	25.2830	263.21	-.10	.00	5.50	-4.90
665	14.8200	25.3000	265.39	-.30	.00	5.70	-4.80
666	14.8870	25.3170	266.07	-.40	.00	5.70	-4.80
667	14.5000	20.7670	187.33	.00	.00	2.40	-2.20
668	14.5000	21.4870	331.51	-2.80	.00	12.50	-8.90
669	14.5000	21.8720	320.83	-1.70	.00	11.30	-8.90
670	14.5000	22.2580	301.91	-.80	.00	9.40	-7.90
671	14.5000	22.6430	272.24	.00	.00	6.40	-6.00
672	14.5000	22.7900	256.83	.70	.00	4.90	-5.30
673	14.5000	22.8600	460.00	.00	.00	.00	.00
674	14.5000	23.0170	290.61	-2.40	.00	8.00	-4.90
675	14.5000	23.1330	460.00	.00	.00	.00	.00

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
676	14.5000	23.2530	284.24	-2.30	.00	7.30	-4.30
677	14.5000	23.4100	460.00	.00	.00	.00	.00
678	14.5000	23.4800	242.37	.50	.00	3.50	-3.70
679	14.5000	23.5830	242.11	.50	.00	3.40	-3.60
680	14.5000	23.6930	241.97	.40	.00	3.40	-3.50
681	14.5000	23.9330	242.62	.20	.00	3.40	-3.40
682	14.5000	24.1670	241.27	.20	.00	3.30	-3.30
683	14.5000	24.4430	238.18	.30	.00	3.00	-3.10
684	14.5000	24.5430	236.24	.50	.00	2.80	-3.00
685	14.5000	24.9000	231.61	.60	.00	2.40	-2.80
686	14.7700	25.1030	258.19	-.10	.00	5.00	-4.40
687	14.8420	25.1030	260.30	-.30	.00	5.20	-4.40
688	14.9130	25.1030	260.99	-.30	.00	5.20	-4.30
689	14.7470	24.9200	252.99	-.10	.00	4.50	-3.80
690	14.8140	24.9010	254.70	-.30	.00	4.60	-3.80
691	14.8800	24.8630	255.22	-.40	.00	4.60	-3.80
692	14.6660	20.6770	180.24	.20	.00	2.20	-2.20
693	14.6660	21.0460	363.11	-11.20	.00	16.20	-3.80
694	14.6660	21.4140	414.15	-11.50	.00	19.50	-6.40
695	14.6660	21.7830	414.03	-10.50	.00	18.90	-7.00
696	14.6660	22.1510	385.47	-8.30	.00	16.20	-6.70
697	14.6660	22.5200	332.80	-4.70	.00	11.70	-6.00
698	14.6660	22.6430	305.70	-2.90	.00	9.40	-5.70
699	14.6660	22.7900	262.69	.20	.00	5.50	-5.30
700	14.6660	22.8600	460.00	.00	.00	.00	.00
701	14.6660	23.0170	285.50	-2.10	.00	7.50	-4.70
702	14.6660	23.1330	460.00	.00	.00	.00	.00
703	14.6660	23.2530	278.25	-2.00	.00	6.30	-4.10
704	14.6660	23.4100	460.00	.00	.00	.00	.00
705	14.6660	23.4800	242.06	.40	.00	3.40	-3.50
706	14.6660	23.6930	255.08	-.70	.00	4.60	-3.40
707	14.6660	23.9330	258.76	-1.10	.00	4.90	-3.30
708	14.6660	24.1670	258.32	-1.20	.00	4.90	-3.20
709	14.6660	24.4430	252.34	-.70	.00	4.30	-3.10
710	14.7770	24.6430	252.64	-.70	.00	4.40	-3.20
711	14.7240	24.6970	249.06	-.40	.00	4.00	-3.20
712	14.6700	24.7500	244.42	.00	.00	3.60	-3.20
713	14.7130	24.8270	249.68	-.20	.00	4.10	-3.50
714	14.7760	24.7990	251.50	-.30	.00	4.30	-3.50
715	14.8400	24.7700	251.98	-.40	.00	4.30	-3.90
716	14.7700	20.6200	180.90	.10	.00	2.40	-2.30
717	14.8360	20.9160	403.26	-15.20	.00	19.70	-3.10
718	14.9020	21.2120	496.33	-20.60	.00	26.50	-4.20
719	14.9680	21.5080	532.18	-21.80	.00	29.00	-4.90
720	15.0340	21.8040	531.84	-21.10	.00	28.70	-5.30

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
721	15.1000	22.1000	503.95	-18.60	.00	26.20	-5.50
722	15.2200	22.2800	479.03	-16.50	.00	24.00	-5.40
723	15.1600	22.5100	429.66	-12.80	.00	19.80	-5.50
724	15.0030	22.5400	390.42	-9.70	.00	16.40	-5.50
725	15.0030	22.6530	336.80	-5.60	.00	12.20	-5.60
726	15.0030	22.7900	270.94	-.10	.00	6.30	-5.70
727	15.0030	22.8600	460.00	.00	.00	.00	.00
728	15.0030	23.0170	283.75	-1.90	.00	7.30	-4.80
729	15.0030	23.1330	460.00	.00	.00	.00	.00
730	15.0030	23.2530	274.57	-1.80	.00	6.50	-4.00
731	15.0030	23.4100	460.00	.00	.00	.00	.00
732	15.0030	23.4800	241.98	.30	.00	3.40	-3.50
733	15.0030	23.6170	256.41	-.90	.00	4.70	-3.40
734	15.0030	23.7230	262.56	-1.40	.00	5.30	-3.30
735	15.0430	23.9330	270.86	-2.20	.00	6.00	-3.20
736	15.0430	24.1670	270.62	-2.20	.00	6.00	-3.20
737	15.0430	24.3830	268.51	-2.10	.00	5.80	-3.10
738	14.8700	20.5670	131.86	.10	.00	2.50	-2.40
739	14.9550	20.7740	389.57	-14.70	.00	18.90	-2.60
740	15.0400	20.9800	499.42	-22.10	.00	27.10	-3.10
741	15.1250	21.1870	560.54	-26.00	.00	32.00	-3.70
742	15.2100	21.3940	589.22	-27.40	.00	33.90	-4.10
743	15.2950	21.6000	593.60	-27.10	.00	34.00	-4.40
744	15.3800	21.8070	579.24	-25.50	.00	32.70	-4.70
745	15.0770	22.5730	460.00	.00	.00	.00	.00
746	15.0770	22.6530	460.00	.00	.00	.00	.00
747	15.0770	22.8600	460.00	.00	.00	.00	.00
748	15.0770	23.1330	460.00	.00	.00	.00	.00
749	15.0770	23.4100	460.00	.00	.00	.00	.00
750	15.0770	23.6170	460.00	.00	.00	.00	.00
751	15.0770	23.7000	460.00	.00	.00	.00	.00
752	15.1130	20.4070	182.88	.10	.00	2.70	-2.60
753	15.2020	20.5450	370.76	-14.10	.00	17.70	-2.20
754	15.2910	20.6820	483.06	-22.10	.00	26.50	-2.40
755	15.3800	20.8200	556.33	-27.20	.00	32.30	-2.60
756	15.4690	20.9580	601.59	-30.20	.00	35.70	-2.80
757	15.5580	21.0950	624.89	-31.50	.00	37.30	-3.00
758	15.6470	21.2330	630.77	-31.50	.00	37.70	-3.20
759	15.2470	22.5730	460.00	.00	.00	.00	.00
760	15.2470	22.6530	460.00	.00	.00	.00	.00
761	15.2470	22.8600	460.00	.00	.00	.00	.00
762	15.2470	23.1330	460.00	.00	.00	.00	.00
763	15.2470	23.4100	460.00	.00	.00	.00	.00
764	15.2470	23.6170	460.00	.00	.00	.00	.00
765	15.2470	23.7000	460.00	.00	.00	.00	.00

NERVA NOZZLE/PRESSURE-VESSEL JOINT -- NOMINAL TEMPERATURES AND SENSITIVITY FACTORS *D* PAGE 18

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)		SF-1 (10% = 30) K	SF-2	SF-3 (10% = 150) NUC HEAT	SF-4 (10% = 10) ρ
766	15.3830	20.2170	184.51	-216	.00	.00	3.00	-2.80
767	15.4640	20.3250	353.88	-107	-13.20	.00	16.70	-2.20
768	15.5450	20.4340	461.13	+1	-21.10	.00	25.10	-2.20
769	15.6270	20.5420	534.05	+74	-26.00	.00	30.90	-2.20
770	15.7080	20.6500	582.02	+122	-29.60	.00	34.60	-2.30
771	15.7890	20.7590	609.77	+149	-31.50	.00	36.60	-2.30
772	15.8700	20.8670	620.09	+160	-32.00	.00	37.50	-2.40
773	15.4030	22.6770	460.00		.00	.00	.00	.00
774	15.4030	22.7670	460.00		.00	.00	.00	.00
775	15.4030	22.8600	460.00		.00	.00	.00	.00
776	15.4030	23.1330	460.00		.00	.00	.00	.00
777	15.4030	23.4100	460.00		.00	.00	.00	.00
778	15.4030	23.5000	460.00		.00	.00	.00	.00
779	15.4030	23.5830	460.00		.00	.00	.00	.00
780	15.6430	20.0100	185.38		.00	.00	3.20	-3.00
781	15.7250	20.0920	337.15		-12.10	.00	15.70	-2.30
782	15.8060	20.1730	436.04		-19.30	.00	23.60	-2.10
783	15.8900	20.2550	505.98		-24.20	.00	29.70	-2.00
784	15.9720	20.3370	553.10		-27.80	.00	32.60	-2.00
785	16.0550	20.4180	580.61		-29.90	.00	34.70	-2.00
786	16.1370	20.5000	590.19		-30.60	.00	35.30	-2.00
787	15.7800	22.6770	460.00		.00	.00	.00	.00
788	15.7800	22.7670	460.00		.00	.00	.00	.00
789	15.7800	22.8600	460.00		.00	.00	.00	.00
790	15.7800	23.1330	460.00		.00	.00	.00	.00
791	15.7800	23.4100	460.00		.00	.00	.00	.00
792	15.7800	23.5000	460.00		.00	.00	.00	.00
793	15.7800	23.5630	460.00		.00	.00	.00	.00
794	16.0000	19.6800	184.96		.00	.00	3.30	-3.00
795	16.0770	19.7560	327.81		-11.60	.00	15.20	-2.40
796	16.1540	19.8320	423.47		-18.40	.00	22.70	-2.10
797	16.2310	19.9080	492.16		-23.40	.00	27.80	-1.90
798	16.3090	19.9650	539.14		-26.90	.00	31.70	-1.90
799	16.3860	20.0610	566.21		-29.00	.00	33.80	-1.90
800	16.4630	20.1370	575.25		-29.70	.00	34.30	-1.90
801	16.3670	19.3330	184.54		.00	.00	3.40	-3.10
802	16.4410	19.4070	323.74		-11.30	.00	15.00	-2.40
803	16.5160	19.4810	418.38		-18.10	.00	22.30	-2.10
804	16.5900	19.5550	486.03		-23.10	.00	27.30	-2.00
805	16.6640	19.6290	531.87		-26.40	.00	31.10	-1.90
806	16.7390	19.7030	558.96		-28.50	.00	33.20	-1.90
807	16.8130	19.7770	567.96		-29.30	.00	33.80	-1.90
808	16.7370	18.9830	183.49		.00	.00	3.50	-3.10
809	16.8090	19.0550	317.26		-10.90	.00	14.70	-2.40
810	16.8800	19.1280	408.08		-17.40	.00	21.30	-2.10

USED FOR JACKET WALL CALC $\bar{T} = +33°F$ $D_T = 20°$

8° DUE TO K
2° " " h
10 " " NUC HEATIN

$\sigma = 20°F$

$\bar{T} = 456°R = -4°F$

$1\sigma = 26°$ AT STA 800.

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
811	16.9520	19.2000	473.30	-22.40	.00	26.20	-2.00
812	17.0240	19.2720	517.33	-25.40	.00	29.90	-1.90
813	17.0950	19.3450	543.19	-27.50	.00	32.00	-1.90
814	17.1670	19.4170	551.86	-28.20	.00	32.70	-1.90
815	17.0830	18.6500	181.94	.00	.00	3.50	-3.10
816	17.1540	18.7180	307.91	-10.30	.00	14.00	-2.50
817	17.2240	18.7870	394.48	-16.40	.00	20.30	-2.10
818	17.2950	18.8550	456.57	-21.30	.00	25.20	-2.00
819	17.3660	18.9230	498.86	-24.20	.00	28.40	-2.00
820	17.4360	18.9920	523.58	-26.00	.00	30.50	-1.90
821	17.5070	19.0600	531.83	-26.70	.00	31.20	-1.90
822	17.4500	18.3030	180.43	.00	.00	3.50	-3.10
823	17.5180	18.3710	301.63	-9.90	.00	13.60	-2.50
824	17.5860	18.4390	384.97	-15.80	.00	19.60	-2.10
825	17.6540	18.5070	444.18	-20.50	.00	24.50	-2.00
826	17.7210	18.5740	484.06	-23.30	.00	27.30	-2.00
827	17.7890	18.6420	507.57	-24.90	.00	29.30	-1.90
828	17.8570	18.7100	515.42	-25.50	.00	30.00	-1.90
829	17.8100	17.9570	178.60	.00	.00	3.40	-3.10
830	17.8750	18.0230	292.42	-9.30	.00	13.00	-2.50
831	17.9410	18.0880	371.69	-15.00	.00	18.60	-2.10
832	18.0070	18.1540	428.20	-19.40	.00	23.40	-2.00
833	18.0720	18.2190	466.58	-22.30	.00	26.20	-2.00
834	18.1380	18.2840	489.11	-23.80	.00	27.80	-1.90
835	18.2030	18.3500	496.62	-24.30	.00	28.50	-1.90
836	18.1700	17.6170	176.92	.00	.00	3.40	-3.10
837	18.2340	17.6810	286.27	-9.00	.00	12.50	-2.50
838	18.2980	17.7450	362.56	-14.60	.00	18.10	-2.10
839	18.3620	17.8090	416.19	-18.50	.00	22.50	-2.00
840	18.4250	17.8720	452.62	-21.40	.00	25.30	-2.00
841	18.4890	17.9360	474.26	-22.90	.00	26.80	-1.90
842	18.5530	18.0000	481.39	-23.40	.00	27.40	-1.90
843	18.5300	17.2730	174.92	.00	.00	3.30	-3.00
844	18.5910	17.3360	278.90	-8.60	.00	12.00	-2.40
845	18.6520	17.3990	352.24	-14.10	.00	17.40	-2.20
846	18.7140	17.4610	403.23	-17.60	.00	21.50	-2.00
847	18.7750	17.5240	438.55	-20.40	.00	24.40	-1.90
848	18.8360	17.5870	459.09	-21.90	.00	25.90	-1.90
849	18.8970	17.6500	465.98	-22.40	.00	26.40	-1.90
850	18.8970	16.9080	171.54	.00	.00	3.10	-2.80
851	18.9560	16.9700	270.34	-8.20	.00	11.60	-2.30
852	19.0150	17.0330	338.10	-13.30	.00	16.80	-2.10
853	19.0730	17.0950	386.99	-16.60	.00	20.10	-1.90
854	19.1320	17.1580	419.71	-19.20	.00	22.90	-1.90
855	19.1910	17.2200	439.83	-20.80	.00	24.50	-1.90

NODE	LENGTH (IN)	RADIUS (IN)	NOMINAL TEMP (DEG-R)	SF-1	SF-2	SF-3	SF-4
856	19.2500	17.2830	446.40	-21.30	.00	25.00	-1.90
857	19.5620	16.2400	169.21	.00	.00	3.20	-2.90
858	19.6820	16.3470	324.46	-12.40	.00	15.90	-2.20
859	19.8020	16.4530	400.55	-17.60	.00	21.40	-1.90
860	19.9220	16.5600	423.92	-19.50	.00	23.40	-1.90
861	21.0270	14.7900	163.06	.00	.00	2.90	-2.70
862	21.1400	14.9000	311.69	-11.90	.00	15.20	-2.00
863	21.2540	15.0100	385.68	-16.90	.00	20.40	-1.70
864	21.3670	15.1200	408.60	-18.60	.00	22.40	-1.70
865	22.4920	13.3540	155.28	.00	.00	2.60	-2.30
866	22.5940	13.4510	279.14	-10.00	.00	12.80	-1.70
867	22.6950	13.5470	341.34	-14.60	.00	17.40	-1.60
868	22.7970	13.6440	360.83	-15.90	.00	18.70	-1.50
869	23.9470	11.9070	147.63	.00	.00	2.20	-2.00
870	24.0400	12.0000	259.91	-9.10	.00	11.50	-1.40
871	24.1340	12.0940	317.42	-13.40	.00	15.90	-1.30
872	24.2270	12.1870	335.26	-14.60	.00	17.10	-1.30
873	25.3910	10.4520	139.74	.00	.00	1.80	-1.60
874	25.4780	10.5390	240.47	-8.20	.00	10.30	-1.20
875	25.5640	10.6250	291.04	-12.00	.00	14.30	-1.10
876	25.6510	10.7120	307.30	-13.20	.00	15.60	-1.10
877	26.8420	8.9980	129.52	.00	.00	1.20	-1.10
878	26.9190	9.0830	221.34	-7.20	.00	8.80	-.70
879	26.9950	9.1680	267.47	-10.70	.00	12.50	-.70
880	27.0720	9.2530	282.20	-11.70	.00	13.60	-.70
881	28.7620	7.0800	118.21	.00	.00	.60	-.50
882	28.8350	7.1500	192.99	-6.00	.00	7.00	-.40
883	28.9090	7.2200	230.77	-8.80	.00	10.00	-.40
884	28.9820	7.2900	242.61	-9.70	.00	10.90	-.30
885	29.9870	6.2700	111.05	.00	.00	.40	-.30
886	30.0250	6.3670	188.63	-6.10	.00	6.90	-.20
887	30.0640	6.4630	227.20	-9.00	.00	10.00	-.20
888	30.1020	6.5600	239.59	-9.90	.00	11.00	-.20
889	31.3550	5.9800	109.36	.00	.00	.40	-.30
890	31.3550	6.0840	187.49	-6.10	.00	6.90	-.20
891	31.3550	6.1880	226.25	-9.00	.00	10.00	-.20
892	31.3550	6.2920	238.59	-9.90	.00	11.00	-.20

DATA CARDS IGNORED - FIRST IS LISTED BELOW

E. METHODS OF CALCULATION

A finite element stress analysis (Reference (b)) was conducted to determine maximum expected stress levels in the 2.0 inch Armco 22-13-5 nozzle flange, using maximum loading conditions. Stress variability was taken from an analysis conducted in February 1971, (Reference (g)). using maximum and nominal stress. was assumed to be 3 sigma, therefore, stress variability D_s was 1/3 the difference between maximum and nominal stress. The maximum stress was reduced by 3 sigma to obtain a mean value for reliability calculation. This method can only provide a preliminary estimate of reliability. More accurate methods have been developed which use the finite element program and propagation of variance techniques to assess the variability of each parameter that affects stress. The techniques are described in Reports N8200 R72-006 and 007. These documents will be included in the Reliability Department Data Package. No actual calculations were made with the new technique due to contract cancellation.

All calculations in this analysis used a sample size of 20 and a confidence level of 90%. The sample size is an estimate based on previous materials test data. The actual sample size for the Armco test data will be between 15 and 24, depending on how much data can be combined. A larger sample size would produce higher reliability values. The confidence level of 90% was used as specified in SNPO-C-1 Appendix V. Any reduction in confidence level would also increase the calculated reliability.

The thermal analysis used for this report was a sensitivity analysis in which mean temperatures were used to establish the material yield strength. The standard deviation for temperature, calculated by the thermal analysis was used to determine a variation in yield strength due to temperature variations. This was then added to the yield strength variation due to testing by the equation

$$D_s = \sqrt{D_s^{\,2}(\text{test}) + D_s^{\,2}(\text{temp})}$$

IV. RECOMMENDATIONS

This analysis is based on materials data derived from a preliminary screening test program of very limited scope. The Armco 22-13-5 forgings have been fabricated for a complete test program. It is recommended that this program be completed, and Class A data be made available before any design changes are made.

It is also recommended that the stress be computed using the finite element program described in Report N8200:R72-007 dtd 20 April 1971. This program will provide updated stress standard deviations (D_s) at all locations.

E

V. REFERENCES

(a) ANSC Drawing 1138000 D Nozzle Layout

(b) ANSC Memorandum N8120 R 72-026 U. A. Pineda to L. A. Shurley dtd 10 March 1972, Subj: Transmittal of Report N8120R:72-026 for Project 141

(c) ANSC Memorandum 8110:R72-029 O. J. Demuth to L. A. Shurley, dtd 15 Feb 1972, Subj: Transmittal of Report 8110:R72-029 and Computer Run JOE, 428237,2,100. 23 Feb 72

(d) ANSC Memorandum N8500:M1432 J. L. Watkins to J. L. Pickering, dtd 30 Nov 1971, Subj: Stress Analysis of Armco 22-13-5 Nozzle P.V. Joint with Upgraded Material Properties

(e) ANSC Memorandum N4310:040 J. Nevenzel to J. L. Watkins, dtd 26 Feb 1971, Subj: Stress Analysis Sensitivity Studies for Reliability Calculations

(f) ANSC Memorandum N8120:068 U. A. Pineda to L. A. Shurley dtd 21 Sept 1971, Subj: Report N8120R:71-005 75K Nozzle/P.V. Pressure Vessel Analysis For Project 141

(g) ANSC Memorandum N8110 R 71-014, dtd 28 Sept 1971 O. J. Demuth to L. A. Shurley, Subj: Transmittal of Report 8110R:71-014 for Project 141.

APPENDIX - INTRODUCTION

SUBJECT SECTION A
RELIABILITY ANALYSIS OF THE NOZZLE FLANGE STRUCTURAL FAILURE MODES.

DATE

WORK ORDER

BY R. L. Ackerman

CHK. BY

DATE 4/12/72

THIS ANALYSIS WILL EVALUATE THE RELIABILITY OF THE NOZZLE FLANGE STRUCTURAL FAILURE MODES AT NORMAL OPERATION.

THIS WILL BE A REVISION TO REPORT NF500; R: 71-1929 WHICH CONTAINED SIMILAR CALCULATIONS ON A 2.4 INCH FLANGE, AND OTHER DIMENSIONAL AND THERMAL DIFFERENCES. IN ADDITION, INCREASED MATERIAL YIELD STRENGTH WILL BE USED IN THIS REPORT TO REFLECT MORE REALISTIC VALUES.

THE FOLLOWING MEAN DIMENSIONS SHOWN IN DRAWING 1138000 D WILL BE USED.

SHEAR LIP RADIUS = 24.3525

FLANGE THICKNESS = 2.0

JACKET SHELL THICKNESS AT MAX STRESS = 0.65

MATERIAL IS ARMCO 22-13-5

STRESS MAX VALUES ARE FROM FINITE ELEMENT PROGRAM, AND REDUCED BY 3σ TO DETERMINE MEAN.

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SUBJECT	REPORT NO.	PAGE iii OF
SECTION A CONTINUED		DATE
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BY RGA	CHK. BY	DATE 4/12/72

THE STRESS VARIABILITY WAS CALCULATED USING THE PETS PROGRAM Ref (e) THIS VARIABILITY WAS THEN USED TO REDUCE THE MAX STRESS TO MEAN STRESS FOR RELIABILITY CALCULATIONS.

LOADING CONDITIONS, FOR MAX STRESS

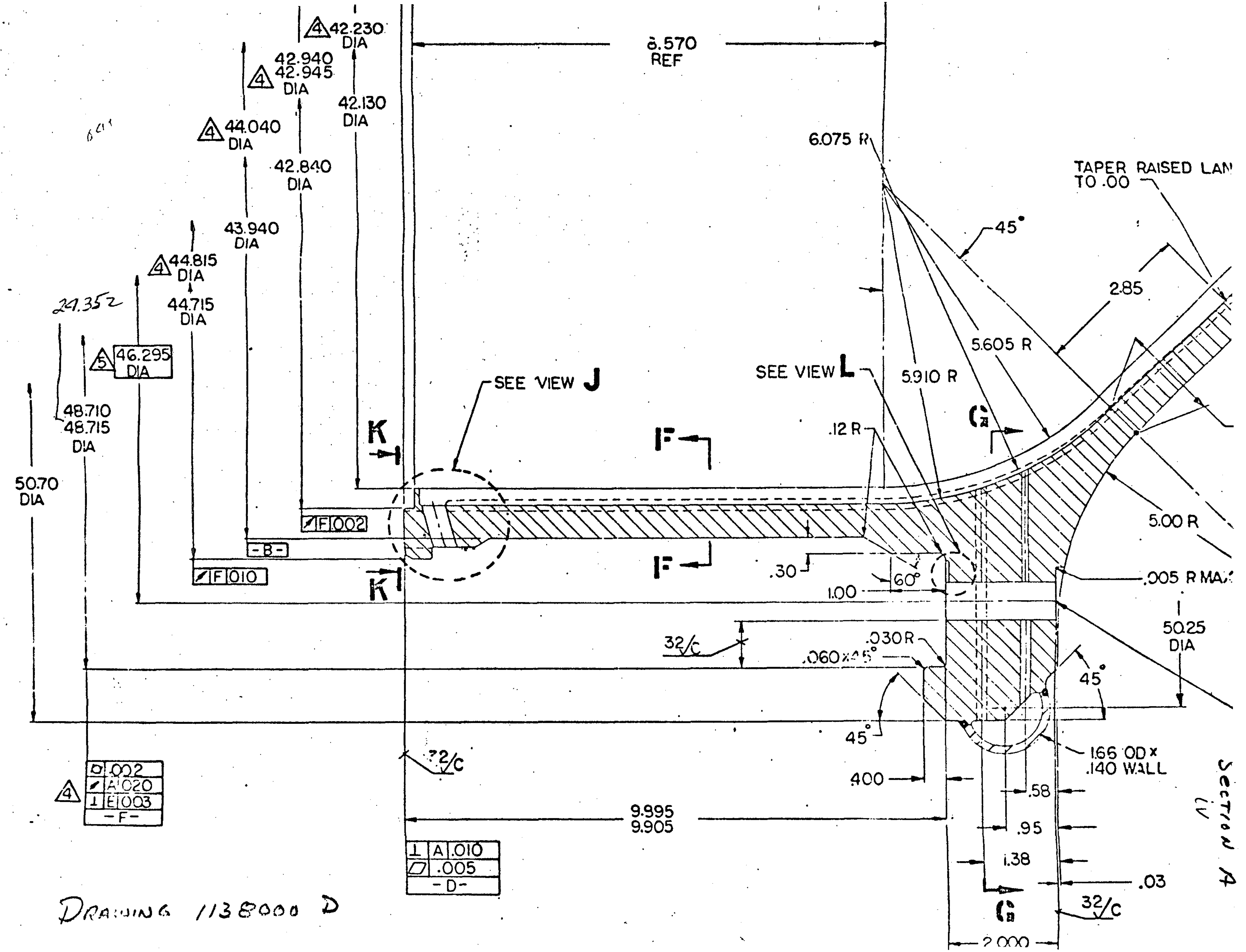
$P_C = 446$ Psi.

$P_{RI} = 1245$ Psi.

$P_{ESO} = 1176$ Psi.

CORE LOAD = 1,110,150 Lb.

MEAN TEMPERATURES WILL BE USED TO DETERMINE MATERIAL YIELD STRENGTH Ref. (c), AND STRENGTH VARIATION DUE TO TEMPERATURE WILL BE INCLUDED IN THE CALCULATIONS.



Drawing 1138000 D

APPENDIX A

LANDS BETWEEN BOLT HOLES

1

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SUBJECT	REPORT NO.	PAGE 2 OF
LANDS BETWEEN BOLT HOLES FMA $\underline{VIII}$ A ARMCO 2.0 INCH FLANGE		DATE
		WORK ORDER
BY R.B. Ackerman	CHK. BY	DATE 4/12/72

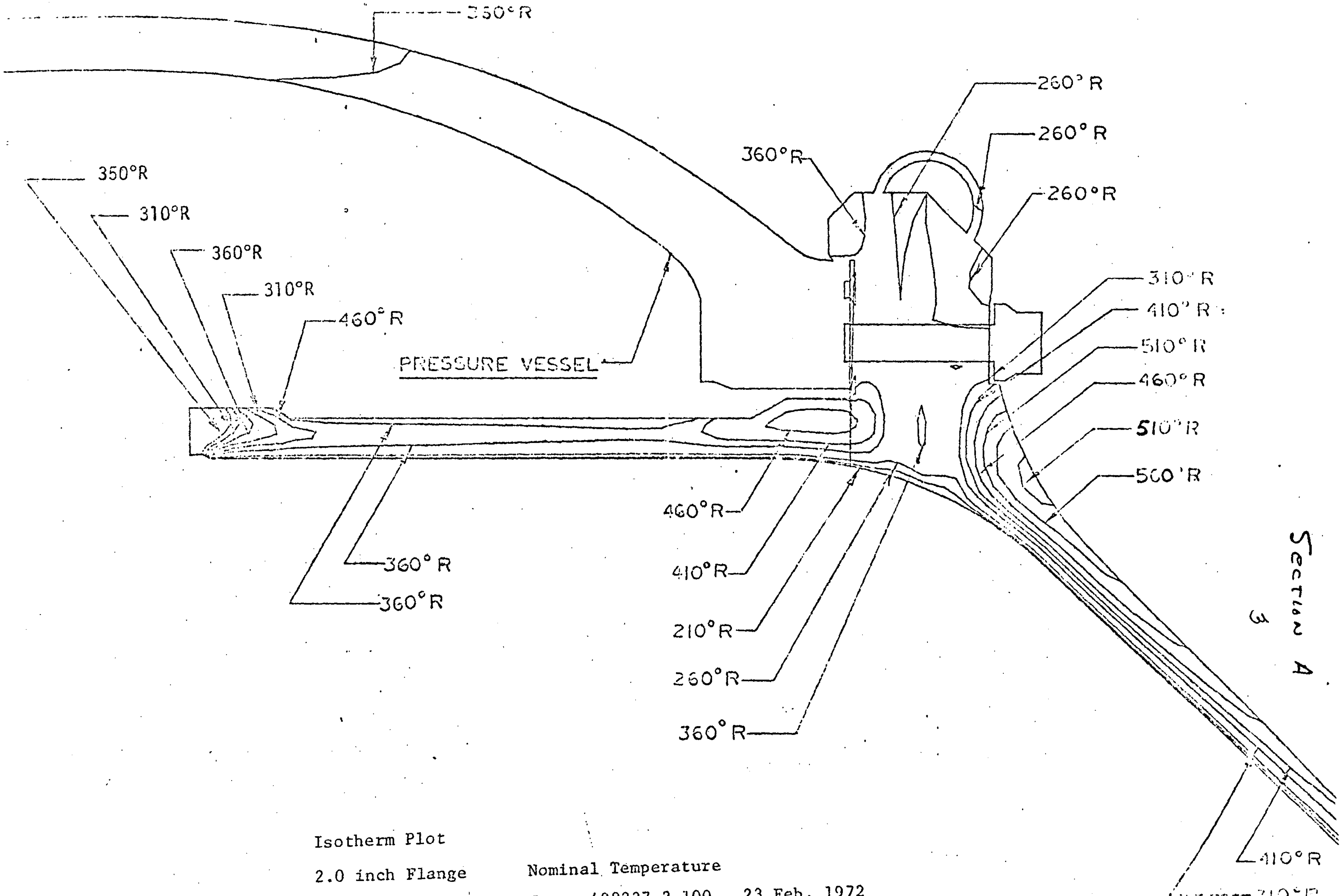
DETERMINE M.S. AND RELIABILITY FOR THE WEB BETWEEN BOLT HOLES OF 2.0 INCH FLANGE.

PRIMARY STRESS HAS BEEN DETERMINED BY FINITE ELEMENT PROGRAM, REF (b.)

$$s_{MAX} = 30,000$$

$$\bar{s} = 30,000 - 3 \ast 896$$
$$= 27312$$

$D_s = 896$ Ref(e) $V_s = 3.3\%$.



Section A
3

Isotherm Plot

2.0 inch Flange — Nominal Temperature

Ref. Computer Run — Joe: 428237,2,100 — 23 Feb. 1972

AGCS-0800-11

REPORT NO.	PAGE 7 OF
SUBJECT: $\overline{VIII}$ A CONTINUED	DATE
	WORK ORDER
BY	CHK. BY	DATE

MATERIAL TEMPERATURE BETWEEN BOLT HOLES. MEAN $= 0^0F + 3\sigma = +27^0F$

MATERIAL PROPERTIES ARMCO 22-13-5

$\bar{S} = 64000$ Psi.

$S_{Des} = 51000$ Psi.

$D_a = 4224$ Psi $\quad V_s = 6.6\%$

SINCE BENDING STRESS IS INCLUDED USE 2 INCREASED PROPERTIES PER SNPO-C-1.

$B_{YK} = \bar{S} * 1.25$

$\therefore \quad \overline{B_{YK}} = 64{,}000 * 1.25 = 80{,}000$

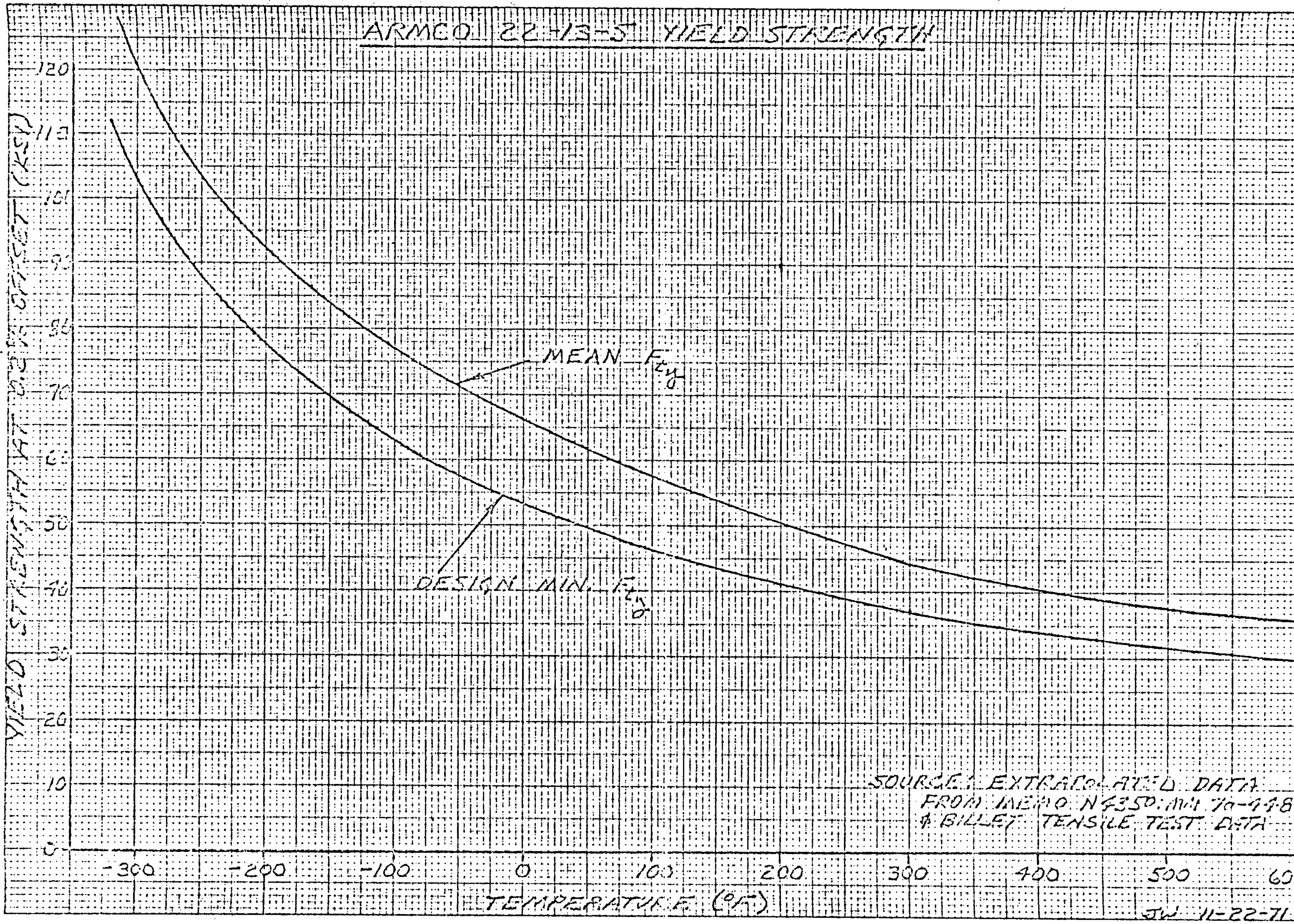
$B_{YK\,Des} = 51{,}000 * 1.25 = 63{,}750$

$$M.S. = \frac{.85 * 63750}{30{,}000} - 1$$

$$= .80$$

NO. 341-10% DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.



SECTION A

Enclosure (1)
N8500:M1432

5

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SUBJECT	REPORT NO	PAGE 26 OF
VIII A CONTINUED		DATE
		WORK ORDER
BY	CHK. BY	DATE

RELIABILITY

$$J = \frac{80{,}000 - 27312}{\sqrt{4224^2 + 896^2}}$$

$$= 12.2$$

RELIABILITY IS .9₂₀

CONCLUSIONS & RECOMMENDATIONS.

(1) THE M.S. AND RELIABILITY FAR EXCEEDS THE REQUIREMENTS, ANY FURTHER REDUCTIONS IN MATERIAL THICKNESS WOULD HAVE TO WAIT UNTIL ADDITIONAL CLASS A MATERIALS DATA IS AVAILABLE.

(2) RECOMMEND A 3 D THERMAL ANALYSIS BE CONDUCTED TO DETERMINE TEMP DISTRIBUTION BETWEEN BOLTS, & BETWEEN COOLANT HOLES.

```
RUN

REL5**      10:51PST    04/19/72

TØLERANCE FACTØR...............?  12.2

EQUIVALENT DEGREES ØF FREEDØM..?  10 DELETED
                                  19.

SAMPLE SIZE FØR MEAN...........?  20.

CØNFIDENCE LEVEL...............?  0.90

              RESULTS------
    1 - RELIABILITY =                              0.73548612E-21
    INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =         9.53694832
```

.9/20

```
READY
```

APPENDIX B

NOZZLE SHEAR LIP

/

AGCS-0800-11

REPORT NO.	PAGE 2 OF

SUBJECT: FMA VIII B NOZZLE SHEAR LIP.
ARMCO 22-13-5 2.0 INCH FLANGE

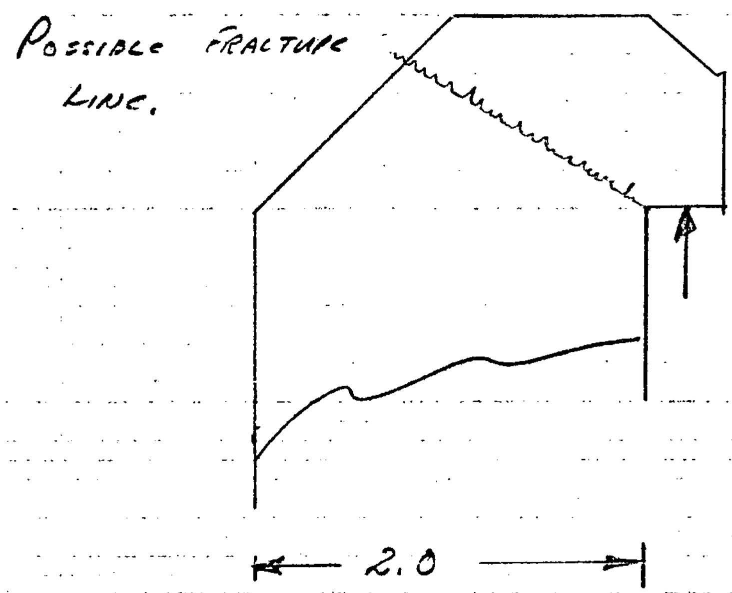
DATE:

WORK ORDER:

BY: R.D. Ackerman.

CHK. BY:

DATE: 9-17-72



COMPUTE RELIABILITY FOR NOZZLE SHEAR LIP
ALONG FRACTURE LINE SHOWN ABOVE.

USE STRESS COMPUTED BY F.E. PROGRAM
Ref. 6.

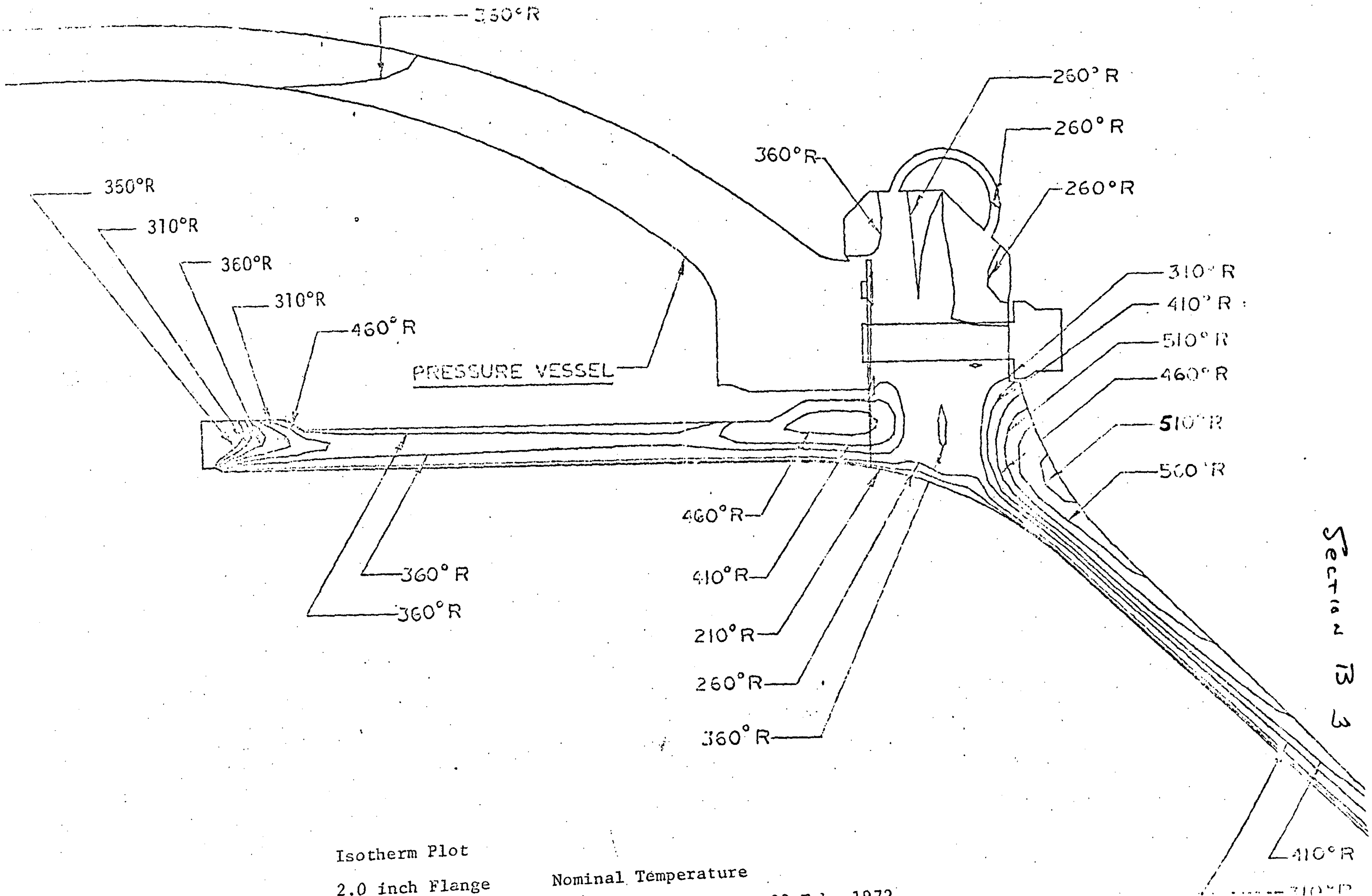
$s_{MAX} = 35000$

$\bar{s} = 35000 - 3 * 606$

$= 33182$

$D_s = 606$ Psi. Ref e

F



Isotherm Plot
2.0 inch Flange
Ref. Computer Run

Nominal Temperature
Joe: 428237,2,100   23 Feb. 1972

MATERIAL PROPERTIES.

THE OPERATING TEMPERATURE OF THE SHEAR LIP IS

$\bar{T} = -50°F$ Ref C

$D_T = 10°$

$T_{MAX} = 0 + 3 * 10 = +30°F$

$\bar{S}_{0°F} = 66{,}000$ Psi.

$S_{Des @ 30°} = 52{,}000$ Psi.

$D_S = 4356$ Psi.

SINCE BENDING STRESS IS PRESENT, ADJUST MATERIALS DATA PER SNPIC-1.

$\bar{B}_{yk} = 1.25 * 66000 = 82{,}500$

$B_{yk\,Des} = 1.25 * 52000 \quad 65000$

$$M.S. = \frac{.85 \times 65{,}000}{35{,}000} - 1$$

$$+0.58$$

$$J = \frac{82{,}500 - 33182}{\sqrt{4356^2 + 606^2}}$$

$$= 10.89$$

RELIABILITY : $.9_{17}$

ALLOCATION REQUIREMENT $.9_{10}88$

CONCLUSION: RELIABILITY AND M.S. EXCEED THE SPECIFIED VALUES. RECOMMEND NO ADDITIONAL DESIGN CHANGES

SUBJECT

Section B Continued

DATE

WORK ORDER

BY

CHK. BY

DATE

```
RUN

REL5**        10:48PST     04/19/72

TØLERANCE FACTØR...............? 10.89

EQUIVALENT DEGREES ØF FREEDØM..?19.

SAMPLE SIZE FØR MEAN...........? 20.

CØNFIDENCE LEVEL...............? 0.90

              RESULTS------
   1 - RELIABILITY =                             0.87610236E-17
   INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =        8.50914514

PRØGRAM STØP AT 350

USED    4.07 UNITS
```

$.9_{17}$ 12

APPENDIX C

NOZZLE / P.V. ATTACHING BOLTS

i

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE ii OF
FMA VIII C. ATTACHING BOLTS.		DATE
		WORK ORDER
BY R.B. Ackerman	CHK. BY	DATE 4/17/72

INTRODUCTION

THE ANALYSIS CONDUCTED ON THE FOLLOWING PAGES WAS COMPLETED IN DEC 1971, AND WILL NOT BE REVISED BECAUSE ALL BOLT LOAD VALUES REPORTED IN REF b ARE THE SAME AS USED IN THIS ANALYSIS REF f

THE BOLT TEMPERATURES WERE NOT CALCULATED IN THE LATEST THERMAL ANALYSIS REF C, THEREFORE THE TEMPERATURES DETERMIN[ED] IN REF g ARE ASSUMED CORRECT.

THE BOLTS MEET RELIABILITY ALLOCATIONS AS FOLLOWS:

	CALCULATED RELIABILITY	ALLOCATED RELIABILITY
STRUCTURAL	$.9_{11}5$	$.9_{10}8$
LEAKAGE	$.9_{7}6$	$.9_{7}$

SUBJECT: FMA VIII C ATTACHING BOLTS LEAKAGE AND STRUCTURAL RELIABILITY.

DATE

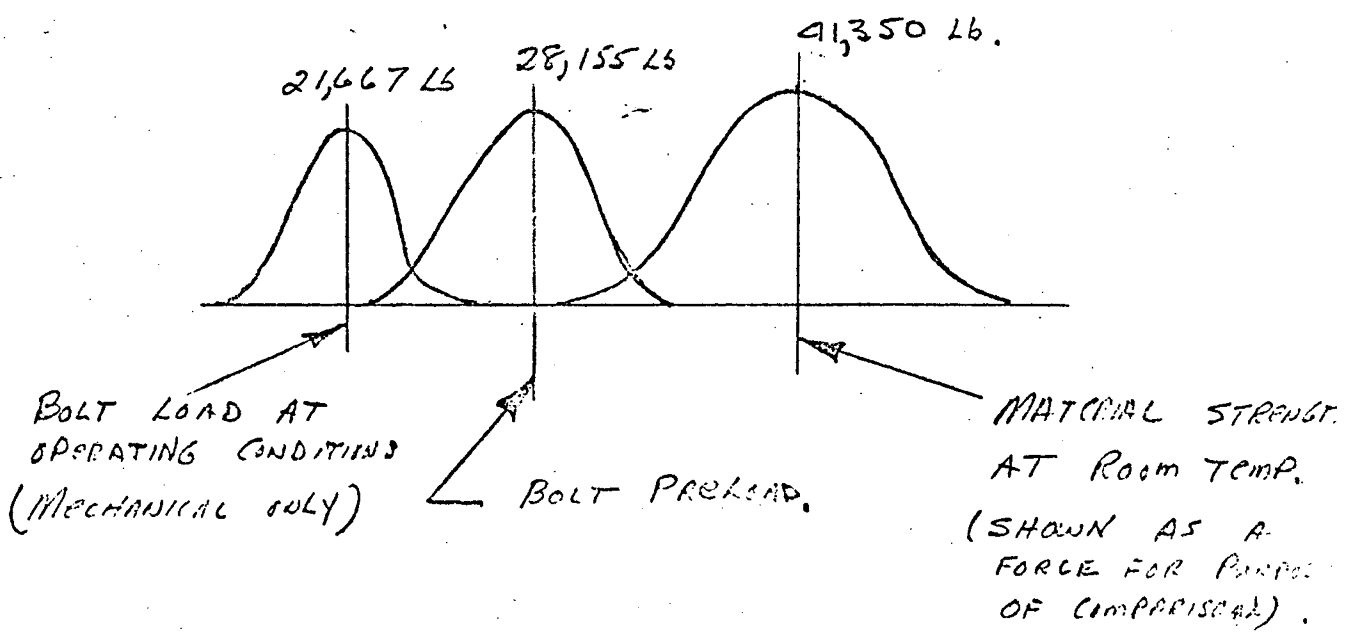
WORK ORDER

BY: R.D. Ackerman | CHK. BY | DATE: 12/17/71

SUMMARY AND CONCLUSIONS.

NOZZLE/P.V. BOLTS MUST BE TORQUED TO A PRELOAD THAT IS EQUAL TO OR GREATER THAN THE MAXIMUM LOAD THAT WILL BE EXPERIENCED DURING ENGINE OPERATION. FAILURE TO PROVIDE ADEQUATE PRELOAD WILL RESULT IN LEAKAGE. THE PRELOAD HOWEVER MUST BE LOW ENOUGH TO MEET THE STRUCTURAL REQUIREM[ENTS] WITH RESPECT TO MATERIAL STRENGTH. THIS ANALYSIS WILL BALANCE PRELOAD WITH ACTUAL LOAD AND WITH BOLT STRENGTH.

THE ACTUAL VALUES ARE SHOWN BELOW:



THE PRELOAD (28,155 LB) IS THE MAXIMUM ALLOWED USING SNPO-C-1 CRITERIA OF .85×DESIGN ALLOWABLE YIELD STRENGTH, AND INCLUDES A REDUCTION TO ALLOW FOR AN 8% VARIATION IN APPLYING THE LOAD.

THE ACTUAL LOAD OF 21667 LB WAS CALCULATED BY THE STRUCTURES DEPT USING THE FINITE ELEMENT PROGRAM. Ref N8120R:71-005.

COMPARING THESE TWO LOADS AND THEIR DISTRIBUTION PRODUCES A RELIABILITY OF $.9_7 6$. THE ALLOCATION FOR LEAKAGE FAILURE MECHANISMS IS $.9_7$

THE MATERIAL ALLOWABLE MEAN LOAD OF 41350 LB WAS FOUND USING TEMPERATURE DETERMINED BY THERMAL ANALYSIS, (Ref N8110R:71-019, AND USING DATA RELEASE MEMO DRM 05.02.

COMPARING THE MATERIAL DISTRIBUTION WITH THE PRELOAD PRODUCED $.9_{11} 5$ RELIABILITY THE ALLOCATION FOR STRUCTURAL MECHANISMS IS $.9_{11}$

THE DESIGN IS THEREFORE ACCEPTABLE PROVIDING BOLT TORQUE IS ACCURATE TO ± 8% OR LESS.

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SUBJECT FMA VIII C Nozzle Bolt		DATE WORK ORDER
BY RGA.	CHK. BY	DATE 1-12-72

Summary Continued

Review of report # 1050 N-R indicates the following;
AND RS-5-0161

1] The torque value is very much a function of the bolt lubricant. The report indicated that the applied load varies significantly if a lubricant is used that is difficult to apply. Sigma was approx. 20% for Neo-LUBE and approx. 8% for Led-Plate. The difference appeared to be in ease of application.

2 The value of applied load for a given torque is very dependent on how well the threads are cleaned after each torque cycle. If the threads are not cleaned properly the load may be too low or binding may occur.

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE iii OF
FMA VIII C ATTACHING BOLTS		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 12/20/71

RECOMMENDATIONS:

1. THE MATERIALS DATA USED FOR THIS ANALYSIS IS VERY INADEQUATE. RECOMMEND A COMPREHENSIVE TEST PROGRAM BE CONDUCTED TO EVALUATE TENSILE YIELD STRENGTH OF A-286 BOLTS AS A FUNCTION OF TEMPERATURE. A TEMP RANGE OF -100°F TO -300°F SHOULD BE USED.

2. THE ANALYSIS INDICATES TORQUE VARIATIONS MUST BE KEPT WITHIN ± 8%. NORMAL EXPECTED TORQUE VARIATION IS ± 25%. THEREFORE IT IS RECOMMENDED THAT A TEST PROGRAM BE CONDUCTED TO DETERMINE THE TORQUING VARIATION THAT WE HAVE USING OUR BOLTS AND THE PROJECTED BOLT LUBRICANT.

SUBJECT FMA VIII C ATTACHING BOLTS, STRUCTURAL RELIABILITY.

DATE

WORK ORDER

BY R.B. Ackerman

CHK. BY

DATE 12/17/71

STRUCTURAL RELIABILITY OF THE BOLTS IS A FUNCTION OF THE BOLT PRELOAD AND MATERIAL STRENGTH AT ROOM TEMP. UNDER OPERATING CONDITIONS, THE LOAD SHOULD REMAIN THE SAME, HOWEVER STRENGTH INCREASES DUE TO COLDER TEMPERATURES.

THE MAXIMUM ALLOWABLE BOLT PRELOAD WILL BE COMPUTED, AND COMPARED WITH THE CALCULATED LOAD UNDER OPERATING CONDITIONS, AND THEN WITH THE MATERIAL YIELD STRENGTH.

BOLT PRELOAD (P_i) (AT ROOM TEMP)

$$P_{i_{MAX\ ALL}} = .85 * S_{DES\ ALL} * A_{CROSS\ SECTION}.$$

$A_{CROSS\ SECTION}$ MUST BE EITHER THE THREAD AREA OR REDUCED SHANK AREA, WHICHEVER IS LESS.

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SUBJECT

NOZZLE BOLTS
SECTION C CONTINUED

DATE	WORK ORDER

BY	CHK BY	DATE
RGA		12/17/71

THREAD AREA A_{TH} =

A_{TH} IS CALCULATED PER THE FOLLOWING FORMULA FOUND IN HANDBOOK H 28

$$A_{TH} = \pi \left[\frac{\text{PITCH DIA}}{2} - \frac{7H}{48} \right]^2 - \text{AREA OF COOLANT HOLE}$$

$H = .866025 * 1/$ NO THREADS /IN.

USE BOLT DRAWING # 1117511 AND SPEC MIL-S-8879.

THE BOLT HAS THE FOLLOWING DIMENSIONS.

BASIC SIZE .6250 -18 UNJF -3A

PITCH DIA = 0.5854
0.5889

THREADS/IN = 18

SUBJECT

NOZZLE BOLTS
SECTION C CONTINUED

DATE

WORK ORDER

BY RGA

CHK. BY

DATE 12/17/71

MINIMUM THREAD AREA

$$A_{TH} = \pi \left[\frac{0.5854}{2} - \frac{7 * .866025 * (1/18)}{48} \right]^2 - \frac{\pi * .135^2}{4}$$

$$= 0.2564 - 0.0143$$

$$= 0.2421$$

MINIMUM AREA IN SHANK PORTION OF THE BOLT

$$A_{SH} = \frac{\pi}{4} \left(.552^2 - .135^2 \right)$$

$$= .2250$$

THE AREA IN THE SHANK IS THE SMALLEST, THEREFORE USE THAT FOR STRESS CALCULATIONS.

MATERIAL ALLOWABLE AT RT = 159,000 PSI.
Ref DRM 5.02 2/29/70

MAX $P_C = .85 * S_{DES} * A_{SH}$ A = BOLT CROSS SECTION AREA

MAX $P_C = .85 * 159,000 * .2250$

$= 30,408$ LB.

THUS 30,408 Lb IS THE MAXIMUM PRELOAD THAT CAN BE APPLIED TO THE BOLT AND SATISFY THE SNAP-C-1 MARGIN OF SAFETY CRITERIA. IF A TORQUE WRENCH IS USED, THE ACCURACY IN APPLYING THE LOAD IS ±25%.

THE MAXIMUM LOAD THAT CAN BE APPLIED ($P_{i\,max}$) MUST BE REDUCED TO GET THE MEAN VALUE ($\bar{P}_i$)...

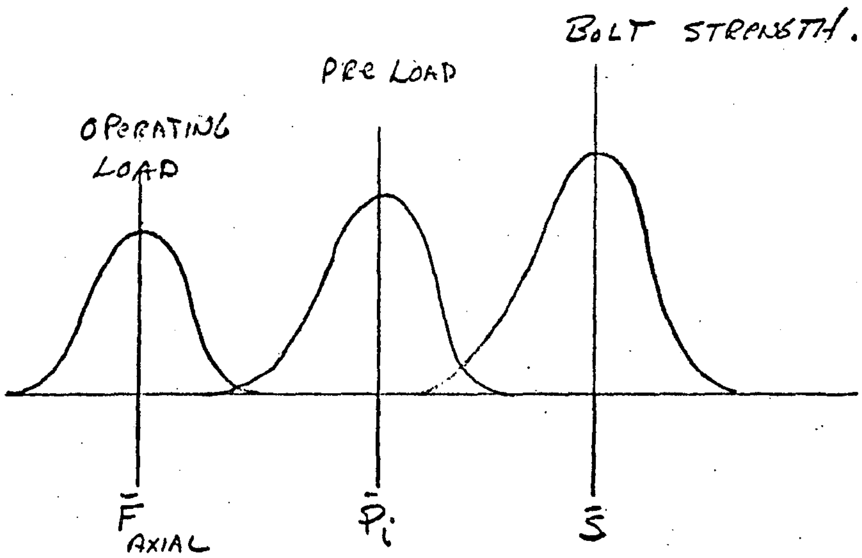
$$\bar{P}_i = \frac{30408}{1.25} = 24{,}326 \text{ Psi.}$$

$$D_{P_i} = (P_{i\,max} - \bar{P}_i)/3$$

$$= (30408 - 24326)/3$$

$$= 2027 \text{ Psi.}$$

THE MEAN PRELOAD ($\bar{P}_i$) MUST NOW BE COMPARED WITH THE MAXIMUM LOAD THE BOLT WILL SEE DURING ENGINE OPERATIONS. THE PRELOAD DISTRIBUTION MUST BE COMPARED WITH THE OPERATING LOAD DISTRIBUTION. IF THE RESULTING RELIABILITY MEETS THE LEAKAGE ALLOCATION, THEN THE PRELOAD DISTRIBUTION MUST BE THEN COMPARED WITH THE MATERIAL STRENGTH DISTRIBUTION TO DETERMINE THE STRUCTURAL RELIABILITY THIS IS SHOWN GRAPHICALLY BELOW.



MUST EVALUATE

$$J = \frac{\bar{P}_i - \bar{F}}{\sigma} \quad \text{AND} \quad J = \frac{\bar{S} - \bar{P}_i}{\sigma}$$

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SUBJECT: NOZZLE BOLTS SECTION C CONTINUED	DATE WORK ORDER
BY: RGA	CHK. BY:	DATE 12/17/71

WE NOW NEED THE CALCULATED LOAD ON THE BOLT DURING ENGINE OPERATION

THIS LOAD HAS BEEN CALCULATED BY L PICKERING AND DOCUMENTED IN EOP N 8120 R: 71-005 Pg 37 DTD 17 SEPT 71. (SEE Pg 6A THIS RPT) THE FINITE ELEMENT PROGRAM WAS USED TO CALCULATE THE LOAD

THE FOLLOWING INPUTS WERE USED TO CALCULATE A MAXIMUM STRESS FOR NORMAL EOL

CHAMBER PRESS P_C = 446 PSI
REFLECTOR INLET PRESS P_{RI} = 1245 PSI
EXT SHIELD OUTLET PRESS P_{ESO} = 1176 PSI
CORE LOAD = 1,110,199 Lb

THE MAXIMUM BOLT LOAD (F) CALCULATED USING THESE INPUTS IS 23292 Lb. AN ADDITIONAL 4000 Lb IS SHOWN AS THERMAL LOAD, HOWEVER THIS IS ADDITIVE TO THE PRELOAD DURING ENGINE OPERATION. NO LOAD VARIATION WAS CALCULATED IN THIS ANALYSIS, HOWEVER PREVIOUS SENSITIVITY STUDIES (REF N4310: 040 DTD 26 FEB 71) INDICATE VARIATION (D_F) IS APPROX 2.5% OF THE MEAN.

SUBJECT SECTION C

DATE 9/13/7

WORK ORDER

BY JLP CHK BY DATE

BOLTS

LOAD IN BOLTS (PG 25 - 36)

	MECHANICAL ONLY	MECH. + THERMAL
$F_{AXIAL\ LOAD}$	18916	18916
$F_{AXIAL\ (MOMENT)}$	2300	(M+T) 4376
$F_{AXIAL\ (\Delta T)}$	—	4000*
F_{TOTAL}	21216	27292
F_{ALL}*	30600*	35600*
M.S.	+.44	+.31
BEARING σ UNDER K-SEAL	59880 PSI	69670 PSI

8000 24000

$*\sigma_{Y\,RT} = 159000$

$\sigma_{ALL} = .85\sigma_{Y\,RT} = 135000$

$F_{ALL_{RT}} = (.227)(135000)$

$= 30600^{\#}$

$*\sigma_{235} \approx 185000$

$\sigma_{ALL} = .85\sigma_{235} = 157000$

$F_{ALL_{235}} = (.227)(157000)$

$= 35600^{\#}$

THE CALCULATED VALUE OF F = 23292 LB
WILL BE CONSIDERED THE UPPER 3σ LIMIT
AND WILL BE REDUCED BY 3 * 2.5% = 7.5%

$$\bar{F} = \frac{23292}{1.075} = 21667 \text{ LB.}$$

$$D_F = 542 \text{ LB.} \qquad (D_F = 2.5\% \text{ of } 21667)$$

$$J = \frac{P_i - \bar{F}}{\sqrt{D_{P_i}^2 + D_F^2}}$$

$$= \frac{24{,}323 - 21667}{\sqrt{2027^2 + 542^2}} = 1.26$$

RELIABILITY IS TOO LOW.

NEXT DETERMINE REQUIRED VALUE OF
P_i AND % VARIATION IN TORQUE THAT
CAN BE ALLOWED.

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SUBJECT: NOZZLE BOLTS
SECTION C CONTINUED

DATE:

WORK ORDER:

BY: RGA

CHK. BY:

DATE: 12/17/71

THE ALLOCATION FOR LEAKAGE IS .9$_7$ 0 J=6.6
IF WE CAN REDUCE THE TORQUE VARIATION
TO ± 15 % THEN

$$\bar{P}_i = \frac{30408}{1.15} = 26442$$

$$D_{P_i} = 1322 \text{ LB.}$$

$$J = \frac{26442 - 21667}{\sqrt{1322^2 + 592^2}} = 3.3$$ STILL TOO LO

REDUCE TORQUE TO ± 10%

$$\bar{P}_i = \frac{30408}{1.10} = 27643$$

$$D_{P_i} = 921$$

$$J = \frac{27643 - 21667}{\sqrt{921^2 + 592^2}} = 5.59$$

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SUBJECT: NOZZLE BOLTS
SECTION C CONTINUED

DATE:

WORK ORDER:

BY: RGA | CHK. BY: | DATE: 12/17/71

REDUCE TORQUE VARIATION TO ± 8%

$$P_i = \frac{30908}{1.08} = 28,155$$

$$D_{P_i} = 750$$

$$J = \frac{28155 - 21667}{\sqrt{750^2 + 592^2}} = 7.0$$

RELIABILITY = <u>.976</u>

~~WE CAN MEET THE LEAKAGE ALLOWANCE~~

IF WE CAN CONTROL TORQUE VARIATION TO <u>± 8%</u> OF THE MEAN. WE MUST TORQUE THE BOLTS TO A MEAN LOAD OF 28155 LB.

NOW EVOLUATE BOLT RELIABILITY USING THE PRELOAD OF 28,155 LB AND D_{P_i} = 750 LB. THESE VALUES WILL BE CONVERTED TO STRESS UNITS.

SUBJECT: NOZZLE BOLTS SECTION C CONTINUED

DATE:

WORK ORDER:

BY: RGA CHK. BY: DATE: 12/17/71

CALCULATE RELIABILITY FOR ASSEMBLY CONDITIONS
(ROOM TEMP WITH NO CHAMBER PRESSURE)

USE PART TOLERENCES SHOWN ON PAGE 11

$$\bar{s} = P_i / \frac{\pi}{4}\left(D_{OD}^2 - D_{ID}^2\right)$$

$$= 28155 / \frac{\pi}{4}\left(.5545^2 - .125^2\right)$$

$$= 122832 \text{ PSI.}$$

$$s_{MAX} = 30408 / \frac{\pi}{4}\left(.552^2 - .115^2\right)$$

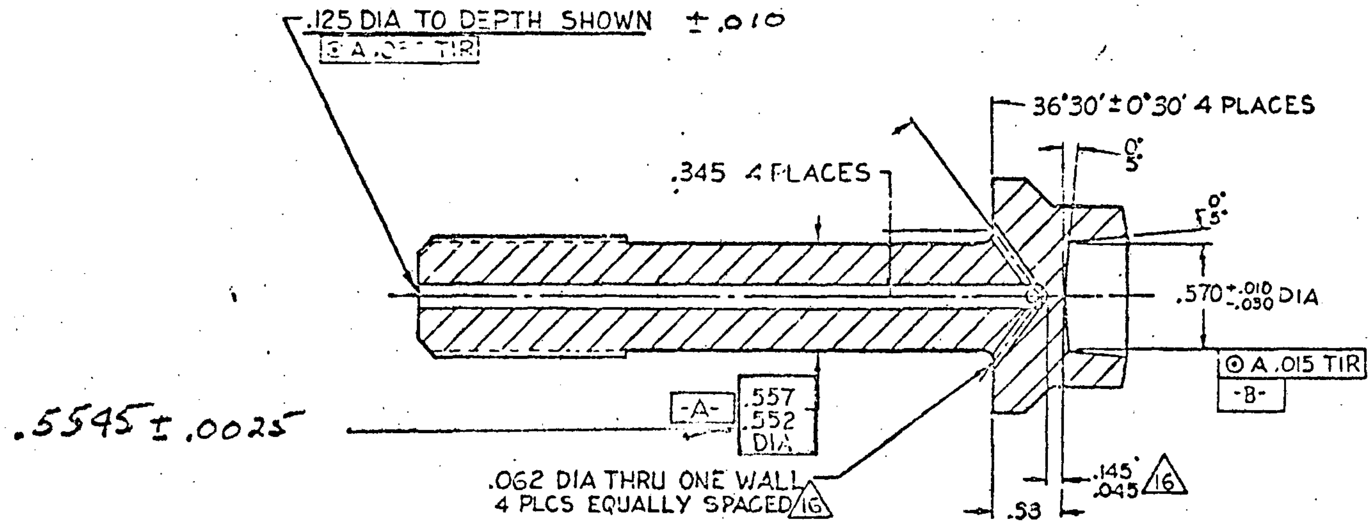
$$= 132828$$

$$D_s = \left(s_{MAX} - \bar{s}\right)/3$$

$$= 132828 - 122832 / 3$$

$$= 3332$$

NOZZLE / P.V. BOLT



SECTION A-A

SECTION C

RGA
12/17/71

P/N 1117511 N/C
RELEASED 6/7/66

SUBJECT

DATE

NOZZLE BOLTS
SECTION C CONTINUED

WORK ORDER

BY RGA

CHK. BY

DATE 12/17/71

MATERIAL PROPERTIES AT ROOM TEMP.

PER DRM - 05.02 DTD 2/16/70

$\bar{S} = 180{,}400$ PSI.

$D_\Delta = 5600$ PSI

DESIGN ALLOWABLE = 159,000 PSI.

$$M.S. = \frac{.85 \times 159{,}000}{132828} - 1$$

$$= +.017$$

$$J = \frac{180{,}400 - 122832}{\sqrt{5600^2 + 3300^2}}$$

$$= 8.85$$

RELIABILITY = $.9_{11}5$ ← ROOM TEMP
ENGINE NOT OPERATI...

THIS EXCEEDS THE STRUCTURAL RELIABILITY GOAL OF $.9_{10}88$ FOR CAT II FAILURES. THEREFORE THE DESIGN IS ACCEPTABLE PROVIDING TORQUE VARIATION CAN BE KEPT WITHIN ± 80%.

CHECK RELIABILITY AT OPERATING TEMP.

NOTE: AT OPERATING TEMP, THE BOLT COOLS DOWN AND THE FLANGE HEATS UP PRODUCING AN ADDITIONAL 4000 LB LOAD WHICH IS ADDED TO THE PRELOAD

NOW $\bar{P}_i \doteq 28155 + 4000 = 32155$ LB

$\text{MAX } P_i = 30408 + 4000 = 34408$ LB.

THE NEW STRESS VALUES ARE.

$$\bar{s} = 32155 \Big/ \frac{\pi}{4}(.5595^2 - .125^2)$$

$$= 140283$$

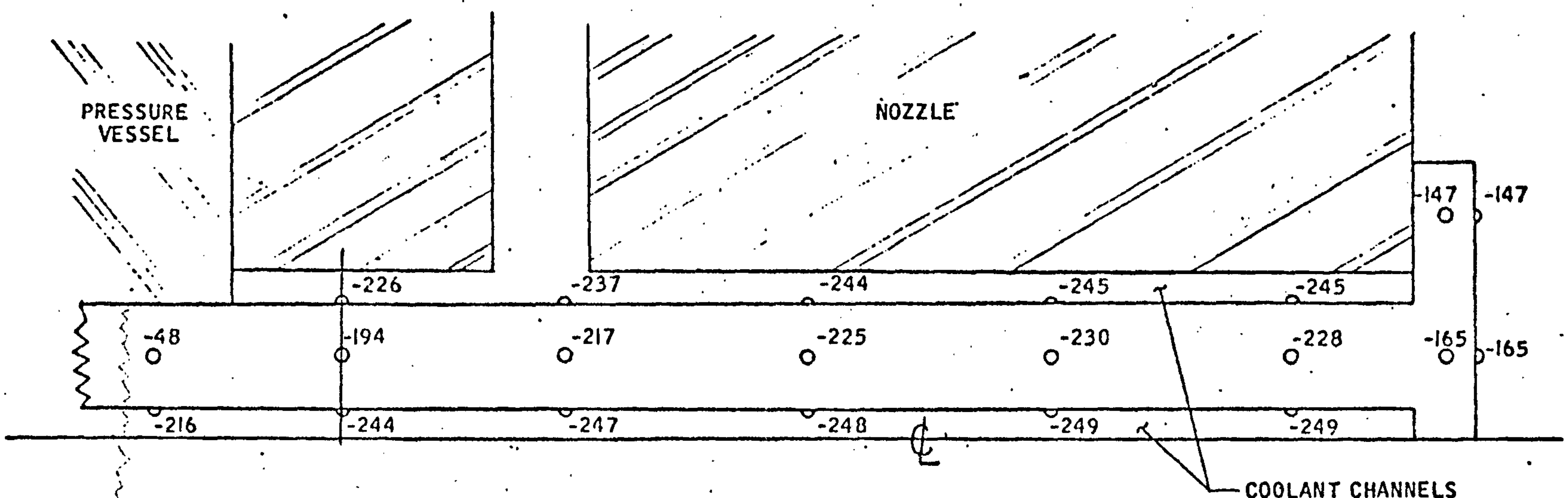
$$s_{MAX} = 34408 \Big/ \frac{\pi}{4}(.552^2 - .115^2)$$

$$= 150301$$

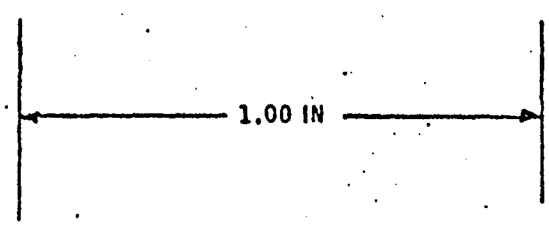
$$D_s = (150301 - 140283)/3$$

$$= 3339$$

COMPUTED BOLT TEMPERATURES
AT THE PRESSURE VESSEL/NOZZLE INTERFACE



BOLT MATERIAL - A286
COOLANT FLOW RATE -- 3 LB/SEC TOTAL FOR 108 BOLTS 2 LB/SEC THROUGH CENTERS
NUCLEAR HEATING -- SPECIFICATION EXTREME
ALL TEMPERATURES SHOWN IN DEG F



Section C 14 12/17/71

FIGURE 8

AGCS-0800-11	REPORT NO.	PAGE 15 OF
SUBJECT: NOZZLE BOLTS SECTION C CONTINUED		DATE:
		WORK ORDER
BY: RGA	CHK. BY	DATE 12/17/71

MATERIAL STRENGTH. AT NORMAL OPERATION END OF LIFE, SPEC EXTREME HEATING RATES, 2 LB/SEC THROUGH BOLT CENTERS.

$T_{MAX} = -215°F$ Ref N8110R: 71-019
JJ WILLIAMS
28 SEPT 71

See Fig on Pg 14.

$\bar{S} = 225000$ PSI. DRM 05.02; 2/24/70 See Pg

$D_S = 5600$ USE Room Temp Variation

Design Allowable = 205000 PSI.

$$M.S. = \frac{.85 * 205000}{150301} - 1$$

$$= +.159$$

$$J = \frac{225000 - 140,283}{\sqrt{5600^2 + 3339^2}} = 12.99$$

RELIABILITY IS GREATER THAN $.9_{15}$

SUBJECT: NOZZLE BOLTS.
SECTION C CONTINUED

DATE:

WORK ORDER:

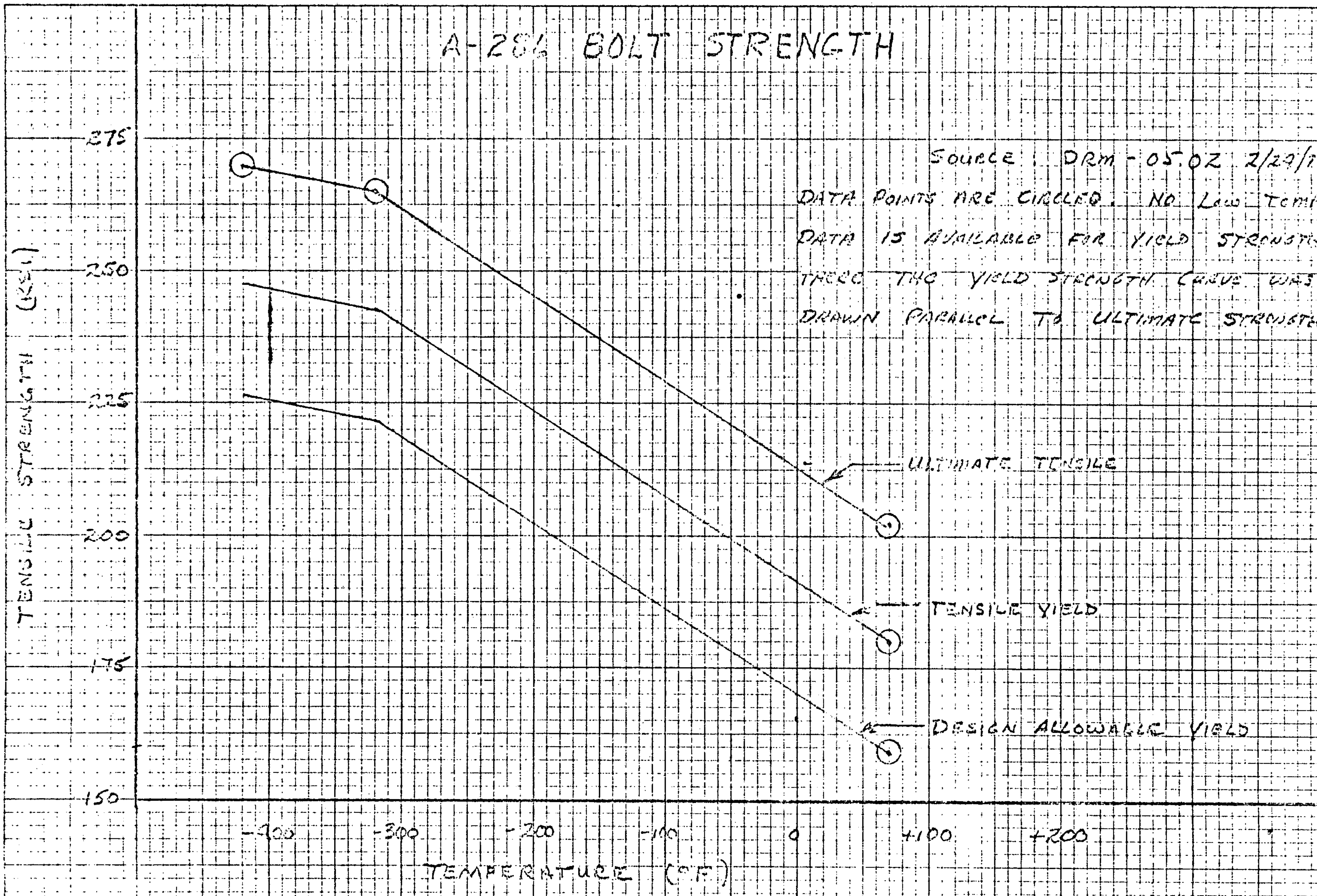
BY: RGA | CHK. BY: | DATE: 12/17/71

RELIABILITY OF THE BOLT AT OPERATING CONDITI..
EXCEEDS $.9_{15}$ DUE TO THE INCREASED STRENGTH AT LOW TEMP. THIS MEANS THAT AS SOON AS ENGINE CHILLDOWN BEGINS ALL BOLT YIELD AND FLANGE LEAKAGE PROBLEMS WILL DISAPPEAR.

THE MOST CRITICAL PROBLEM IS TO CHOOSE THE CORRECT PRELOAD TO INSURE THAT OPERATING LOAD WILL NEVER EXCEED PRELOAD, AND YET THE PRELOAD WILL NOT CAUSE YIELDING UNDER ROOM TEMP ASSEMBLY CONDITIONS.

NO. 340A-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.



12/17/71 17

SECTION 'C'

C4

APPENDIX D

JACKET MEMBRANE

/

AGCS-0800-11

SUBJECT		REPORT NO	PAGE 1a OF
JACKET MEMBRANE FMA VIII D P/N 1138000 D			DATE
			WORK ORDER
BY R.D. Ackerman	CHK. BY		DATE 4/17/72

CALCULATE RELIABILITY OF 0.65 INCH THICK JACKET, USING STRESS FROM FINITE ELEMENT COMPUTER PROGRAM, AND VARIANCE FROM PROPOGATION OF VARIANCE CALCULATION.

STRESS MAX = 29,300 PSI (Ref 6)

STRESS VARIATION

$$D_\sigma^2 = \left(\frac{\bar{R}}{\bar{\tau}} D_P\right)^2 + \left(\frac{\bar{P}}{\bar{\tau}} D_R\right)^2 + \left(\frac{PR}{\tau^2} D_\tau\right)^2$$

$$D_\sigma^2 = \left(\frac{19.640}{.61} \times 3\right)^2 + \left(\frac{450}{.61}\ .0033\right)^2 + \left(\frac{19.640 \times 450 \times .010}{.61^2}\right)^2$$

D_σ = 256 PSI.

WHERE PRESSURE P = 450 D_P = 3

RADIUS R = 19.640 D_R = .0033

*THICKNESS τ = .66 - .05 = .61 D_τ = .01

* τ IS REDUCED BY .05 TO ALLOW FOR TUBE GROOVES.

SECTION D CONTINUED

MEAN STRESS $= \bar{s} = 28000 - 3 * 256$

$\bar{s} = 27,232$

MATERIAL OPERATING TEMPERATURE PER REFERENCE C

5 DATA POINTS AT THE .66 INCH CROSS SECTION WERE USED. TO DETERMINE MEAN TEMP. THE TEMPERATURE VARIATION WAS THEN ADDED TO THE MEAN TO ARRIVE AT A VALUE TO USE IN DETERMINING MATERIAL STRENGTH.

$\bar{T} = 90°F$

* $D_T = 20°F$

$T_{MAX} = 90 + 3 * 20$ $\underline{\underline{150°F}}$

* D_T INCLUDES 8° VARIATION DUE TO THERMAL CONDUCTIVITY
10° " " " NUCLEAR HEATING
2° " " " HEAT TRANSFER COEFF.

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE 3 OF
JACKET WALL SECTION D CONTINUED		DATE
		WORK ORDER
BY RGA	CHK. BY	DATE 4/18

MATERIAL PROPERTIES FOR 0.65 INCH JACKET

$T_{MAX} = 90^\circ F$

$T_{MEAN} = 30^\circ F$

$D_T = 20^\circ F$ (Ref c)

$\bar{S}_{30} = 63000$ Psi (Ref d)

$S_{DES(90^\circ)} = 47{,}000$ Psi. (Ref d)

$D_S^2 = (\text{Variation Due To Testing})^2 + (\text{Variation Due To Temp})$

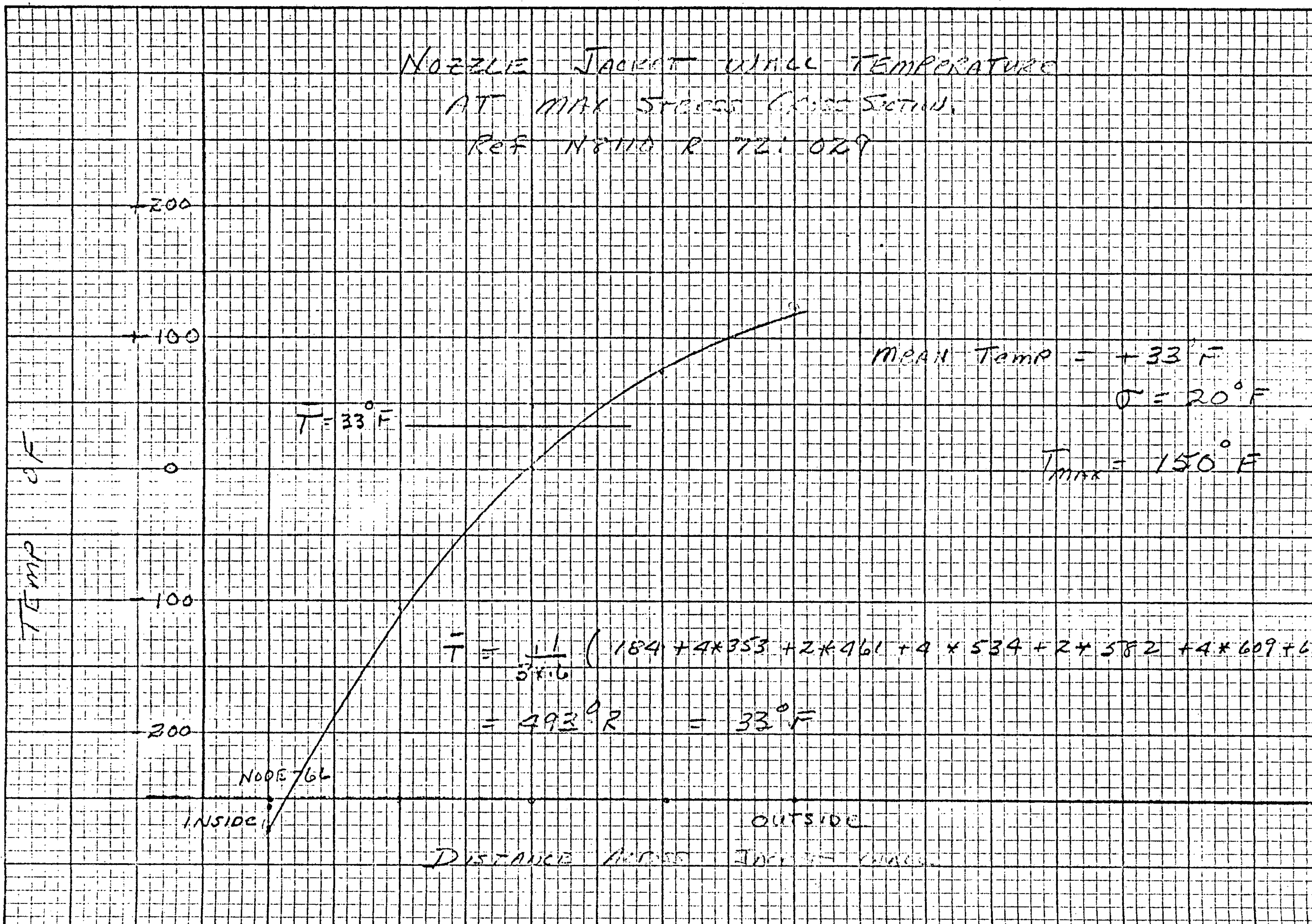
Variation Due To Testing $(D_{S-D}) = 3828$ Psi.

Variation Due To Temp $(D_{S-T}) = 1000$ Psi.

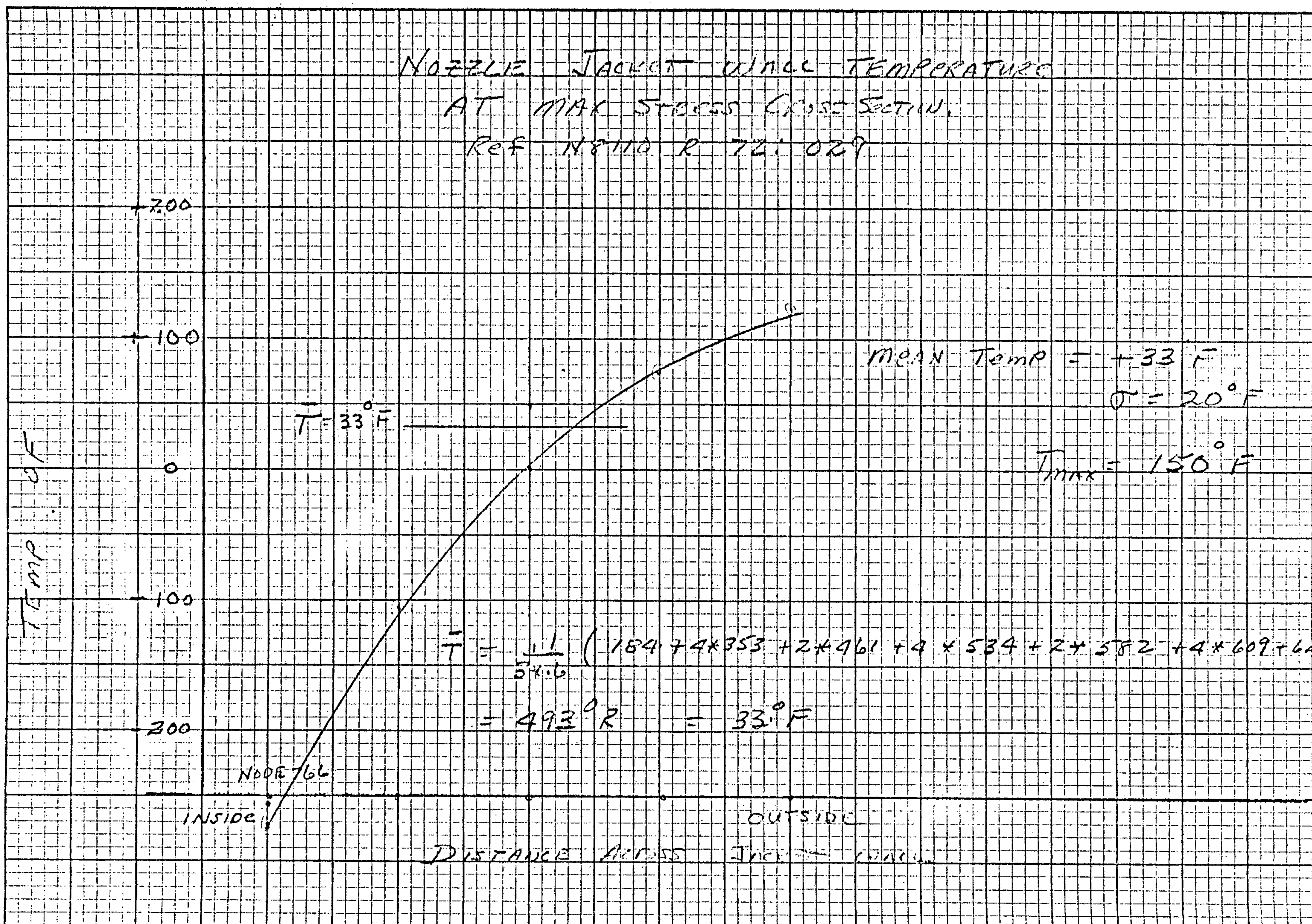
$D_S = \sqrt{3828^2 + 1000^2}$

$= 3956$ Psi

K+E 5 X 5 TO ½ INCH 46 0860
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

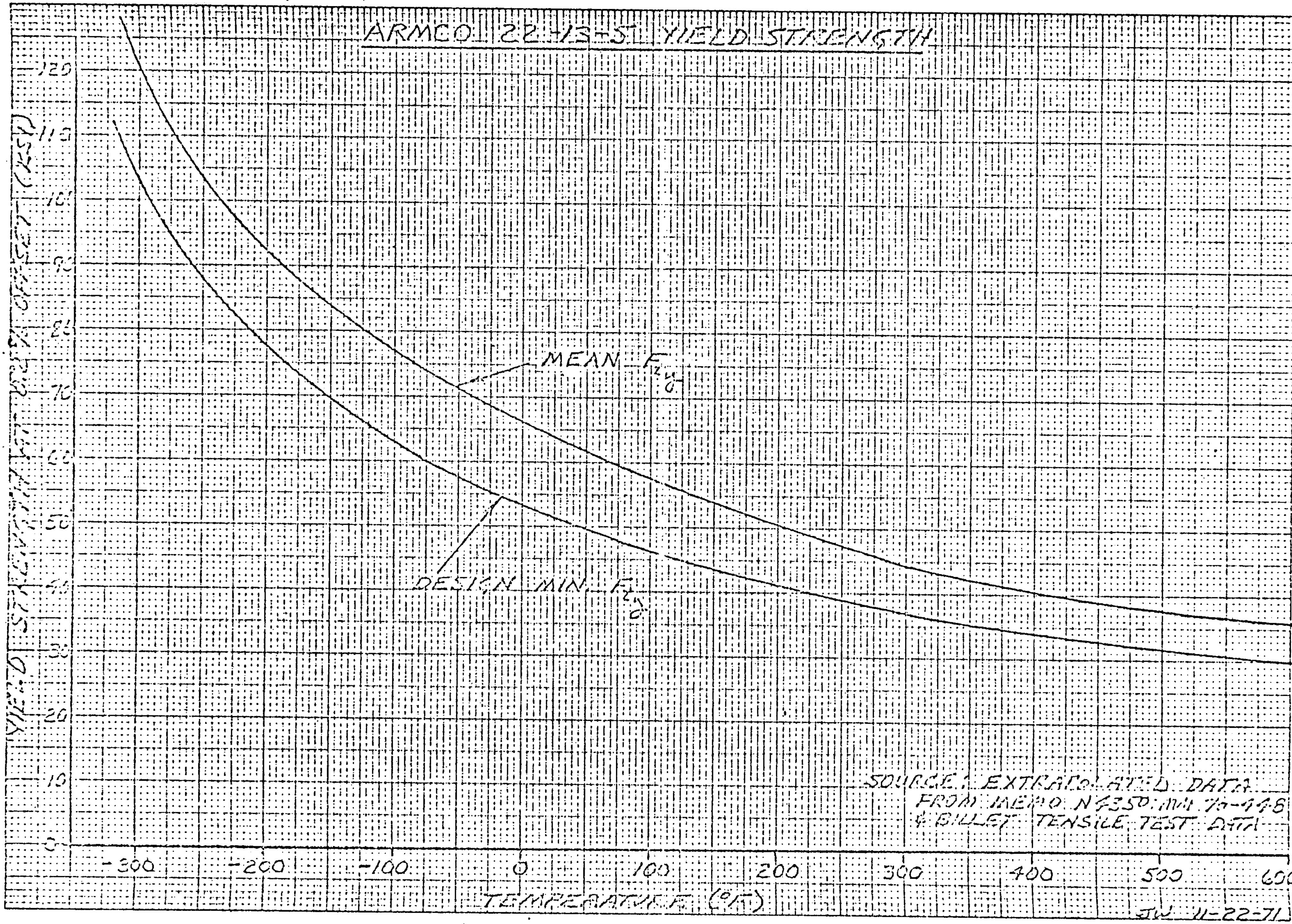


SECTION 3.2


NOZZLE JACKET WALL TEMPERATURE
AT MAX STRESS CROSS SECTION.
+200
+100
0
-100
-200
TEMP °F
$\bar{T} = 33°F$
MEAN TEMP = +33 F
$\sigma = 20°F$
$T_{MAX} = 150°F$
$\bar{T} = \frac{1}{5 \times 6}(184 + 4*353 + 2*461 + 4*534 + 2*582 + 4*609 + 620)$
$= 493°R = 33°F$
NODE 766
INSIDE
OUTSIDE
DISTANCE ACROSS JACKET WALL

3-6

RLA 1/1/..



Section D

Enclosure (1)
N8500:M1432 3-C

AGCS-0800-11

REPORT NO	PAGE 4 OF
SUBJECT: NOZZLE JACKET WALL , .66 THICK. SECTION D CONTINUED	DATE
	WORK ORDER
BY: RGA. CHK. BY	DATE 4/18/72

$$M.S. = \frac{.85 * 47,000}{29,300} - 1$$

$$= + 0.36$$

$$J = \frac{63,000 - 27538}{\sqrt{3956^2 + 256^2}}$$

$$= 8.67$$

RELIABILITY $= .9_{11}41$

THE CALCULATED RELIABILITY FOR THE 0.66 INCH JACKET WALL IS JUST ABOVE THE ALLOCATION OF 9_{10} 8P. THE MATERIAL STRENGTH MUST BE DETERMINED BY MORE EXTENSIVE TESTS, HOWEVER ASSUMING IT DOES NOT CHANGE THE DESIGN IS ACCEPTABLE.

SUBJECT
SECTION D CONTINUED

DATE

WORK ORDER

BY

CHK. BY

DATE

```
RUN

REL5**       12:27PST     04/20/72

TØLERANCE FACTØR...............?8.69

EQUIVALENT DEGREES ØF FREEDØM..? 2 DELETED
                                  19

SAMPLE SIZE FØR MEAN...........? 20

CØNFIDENCE LEVEL...............?0.90

              RESULTS------
   1 - RELIABILITY =                              0.59370349E-11
   INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =         6.78173554

READY
```

$= 9.41$ 11

SUBJECT: JACKET MEMBRANE SECTION D CONTINUED

DATE

WORK ORDER

BY: R.S. Ackerman | CHK. BY | DATE 5/18/72

COMPUTE RELIABILITY OF MERIDIONAL STRESS IN NOZZLE SHELL AT MAX STRESS LOCATION

JACKET WALL IS .65 INCHES THICK AT THE MAX STRESS LOCATION Ref DRAWING NO 1138000 D. (2.0 INCH FLANGE)

STRESS MAXIMUM WAS COMPUTED BY FINITE ELEMENT COMPUTER PROGRAM (Ref b). THIS IS A COMBINATION PRIMARY + BENDING STRESS.

STRESS

$s_{MAX} = 28,000$ PSI. (Ref b)

NO STANDARD DEVIATION FOR STRESS (D_s) HAS BEEN CALCULATED, AND PROPOGATION OF VARIANCE TECHNIQUES CAN NOT BE APPLIED IN THIS CASE BECAUSE THE STRESS IS A COMBINATION OF BENDING + PRIMARY AND NO CLOSED FORM SOLUTION IS AVAILABLE.

THEREFORE ASSUME D_Δ IS THE SAME AS THE D_Δ FOR HOOP STRESS CALCULATED ON Pg 1

$D_\Delta = 256$ PSi. Pg 1 OF THIS ANALYSIS

$\bar{A} = 28{,}000 - 3 * 256 = 27232$ PSi.

<u>MATERIAL PROPERTIES.</u>

MATERIAL TEMPERATURE IS DETERMINED BY A NOMINAL CASE THERMAL ANALYSIS PLUS A SENSITIVITY ANALYSIS. Ref C. (THE COMPUTER OUTPUT IS SHOWN IN THIS REPORT.

$\bar{\bar{T}} = 115°F$ (Ref C & ISOTHERM IN THIS REPORT)

$D_T = 26°F$

$T_{MAX} = 193°F$

MATERIAL STRENGTH.

$\bar{S}_{115°F} = 57000$ PSI.

$S_{DESIGN\ 193°} = 41{,}000$ PSI.

VARIATION DUE TO TESTING = 3762 PSI.

VARIATION DUE TO TEMPERATURE = 1000 PSI.

$D_S = \sqrt{3762^2 + 1000^2}$

$= 3892$ PSI.

SINCE BENDING IS INVOLVED IN TOTAL STRESS, MATERIAL STRENGTH IS MULTIPLIED BY 1.25 PER SNPO C-1

$\therefore\ \bar{S} = 57000 \times 1.25 = 71{,}250$

$S_{DES} = 41{,}000 \times 1.25 = 51250$

SUBJECT JACKET MEMBRANE SECTION D CONTINUED

DATE

WORK ORDER

BY RGA

CHK. BY

DATE 5/18/72

$$M.S. = \frac{.85 * 51250}{28,000} - 1$$

$$= .56$$

$$J = \frac{\overset{48,758}{71,250} - 27232}{\sqrt{3892^2 + 256^2}} = 11.28$$

RELIABILITY = .9₁₈4.

REL5** 13:22PDT 05/18/72

TØLERANCE FACTØR...............?11.28

EQUIVALENT DEGREES ØF FREEDØM..?19

SAMPLE SIZE FØR MEAN...........?20

CØNFIDENCE LEVEL...............?0.90

RESULTS------

1 - RELIABILITY = 0.59747208E-18 $= .9_{18}4$

INVERSE ØF NØRM. CUM. DIST. FUNCTIØN = 8.81517863

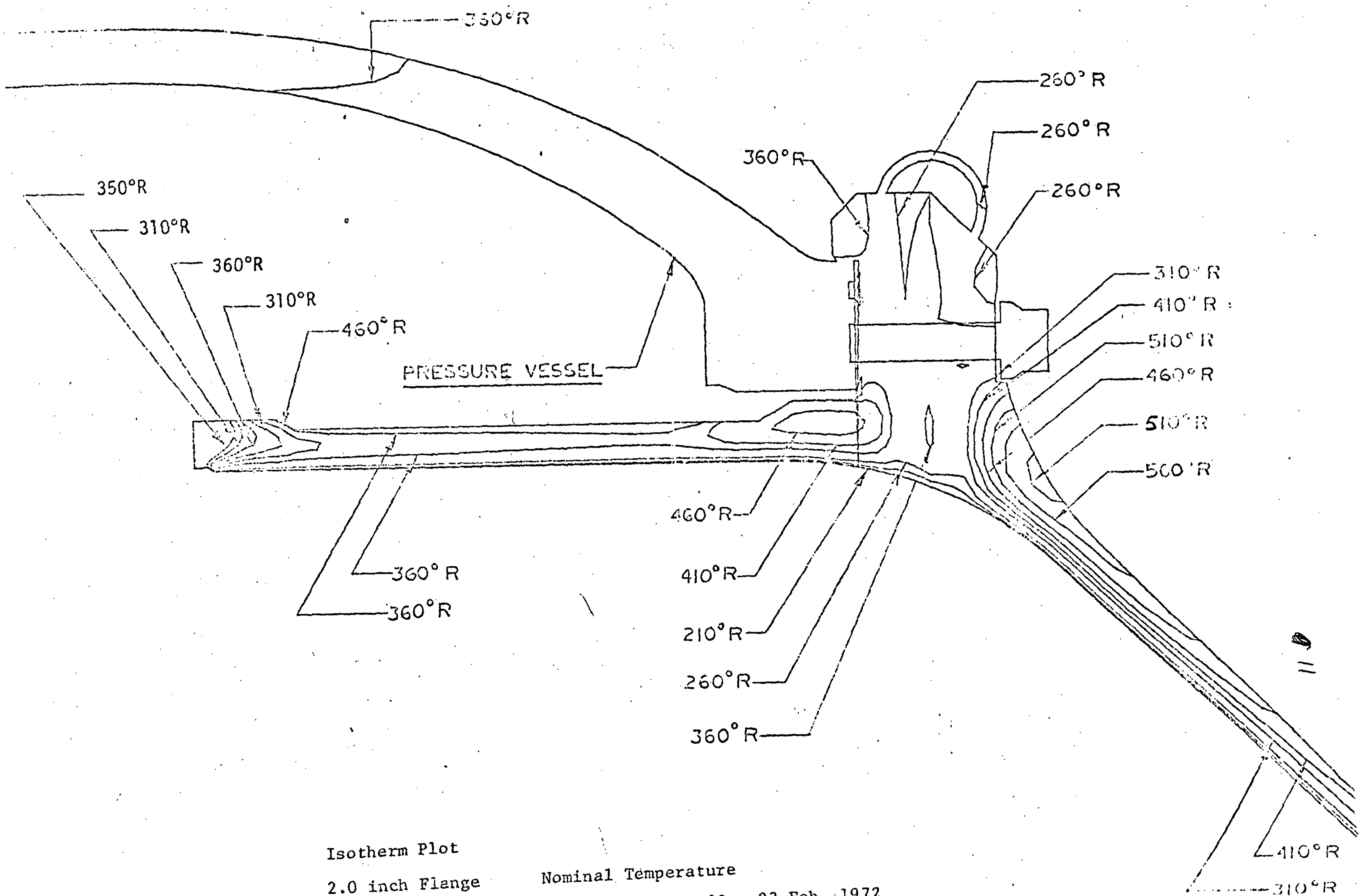
B

AGCS-0800-11

	REPORT NO.	PAGE 10 OF
SUBJECT: JACKET MEMBRANE SECTION D CONTINUED		DATE
		WORK ORDER
BY: RG Ackerman	CHK. BY	DATE 5/18/72

SUMMARY

M.S. AND RELIABILITY ARE ABOVE THE ALLOCATION FOR THE CALCULATED MERIDIONAL STRESS. NOTE HOWEVER THAT THE MAXIMUM TEMPERATURE USED IS LOWER THAN THAT USED IN THE STRESS ANALYSIS REF 6. THE TEMPERATURES USE HERE ARE MEAN + 3σ WHILE THE SPEC EXTREME VALUES WERE USED IN REF 6. THIS MAKES A SIGNIFICANT DIFFERENCE IN THIS CASE CALCULATIONS (NOT SHOWN) INDICATE THAT AT SPEC EXTREME TEMP, THE RELIABILITY GOES DOWN TO .9₉, WELL BELOW THE ALLOCATION OF .9₁₀88.



Isotherm Plot
2.0 inch Flange Nominal Temperature
Ref. Computer Run Joe: 428237,2,100 23 Feb. 1972

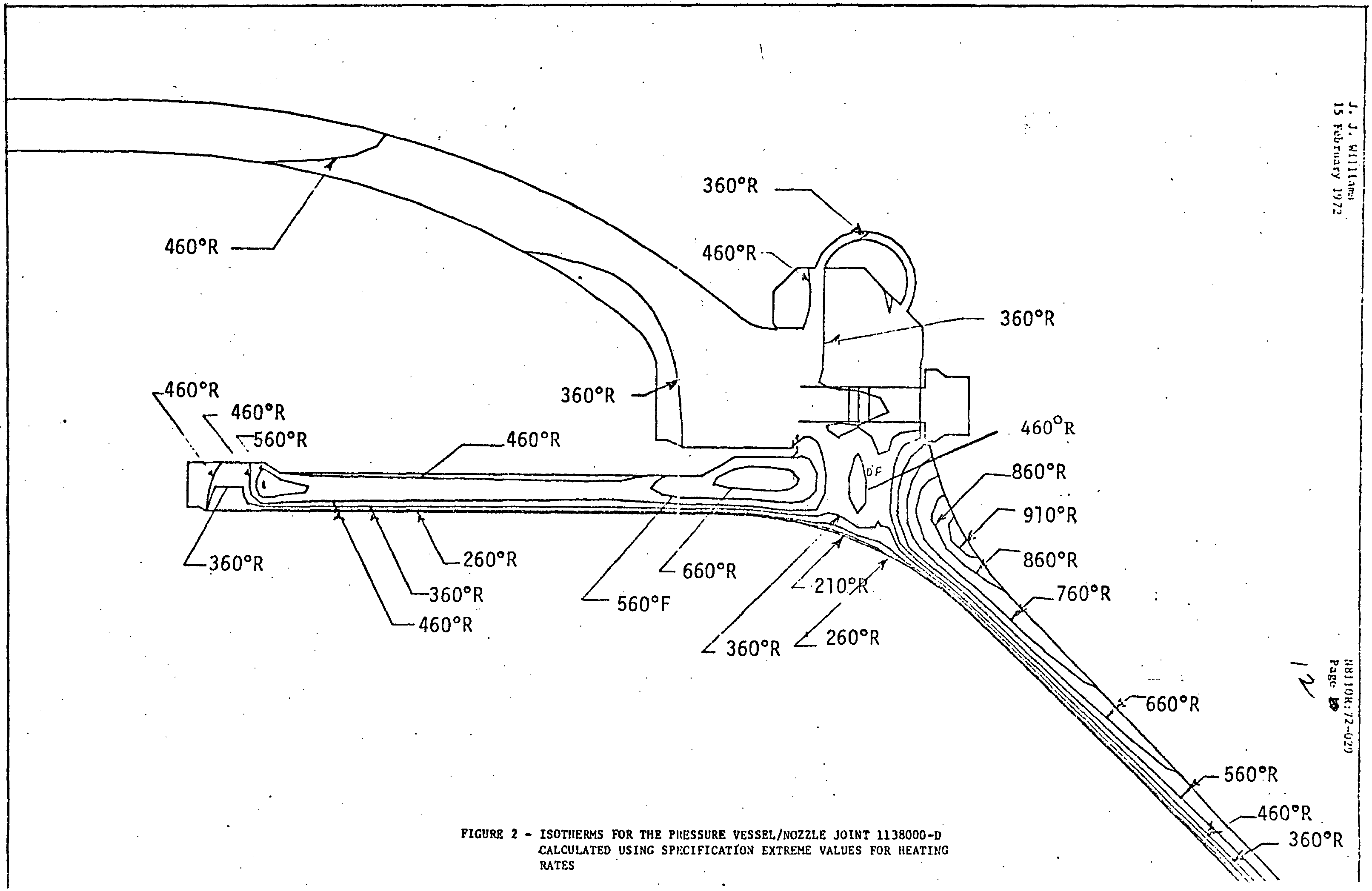


FIGURE 2 - ISOTHERMS FOR THE PRESSURE VESSEL/NOZZLE JOINT 1138000-D CALCULATED USING SPECIFICATION EXTREME VALUES FOR HEATING RATES

APPENDIX E

CORE SUPPORT

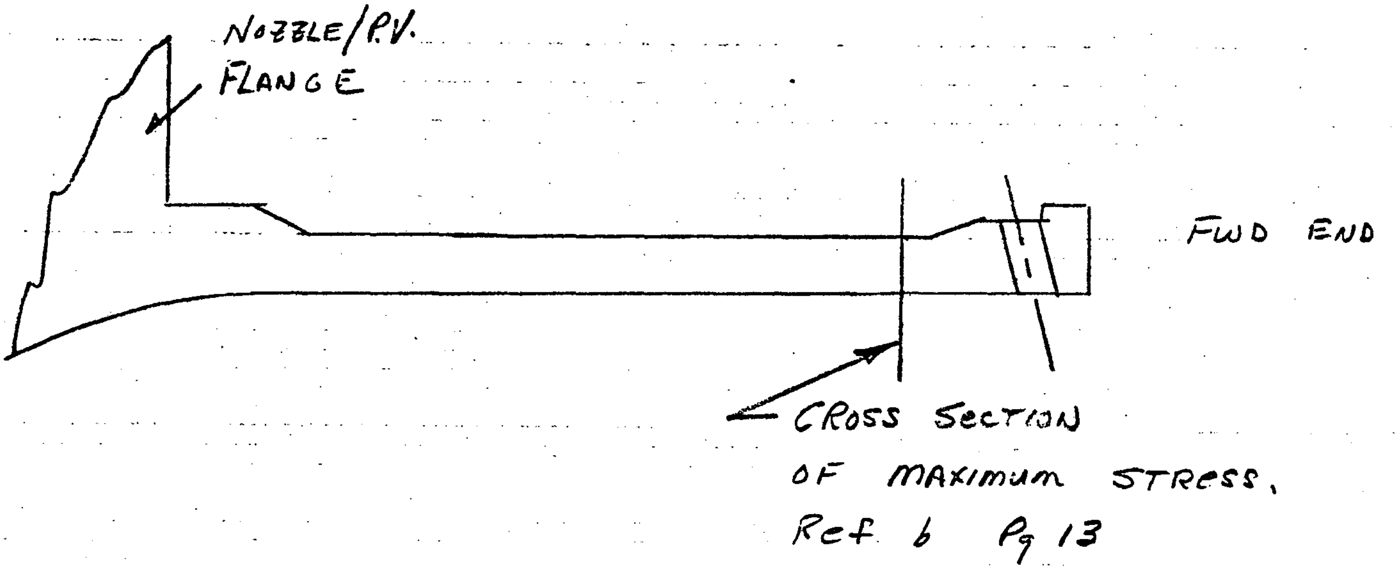
/

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE 1-a OF
CORE SUPPORT HOOP MEMBRANE STRESS. FMA VIII E		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 4/18/72

EVALUATE MS & RELIABILITY OF CORE SUPPORT DUE TO HOOP MEMBRANE STRESS ONLY

STRESS WAS CALCULATED BY FINITE ELEMENT COMPUTER PROGRAM. (Ref b)



MAXIMUM STRESS

Δ_{MAX} = 33,500 PSI. (Ref b)

D_{Δ} = 544 (Ref e)

$\bar{\Delta}$ = 33500 − 3 * 544

$\bar{\Delta}$ = 31,868

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE 2 OF
CORE SUPPORT. SECTION E CONTINUED		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 4/17/72

MATERIAL TEMPERATURE. (PER REF C). AND ATTACHED GRAPH.

$\bar{T} = -83°F$

$D_T = 22°$

$T_{MAX} = -17\ F \leftarrow (-83 + 3 * 22°)$

MATERIAL PROPERTIES.

$\bar{S}_{-83°F} = 75{,}000$

S_{DCS} AT $-16°F = 54{,}000$

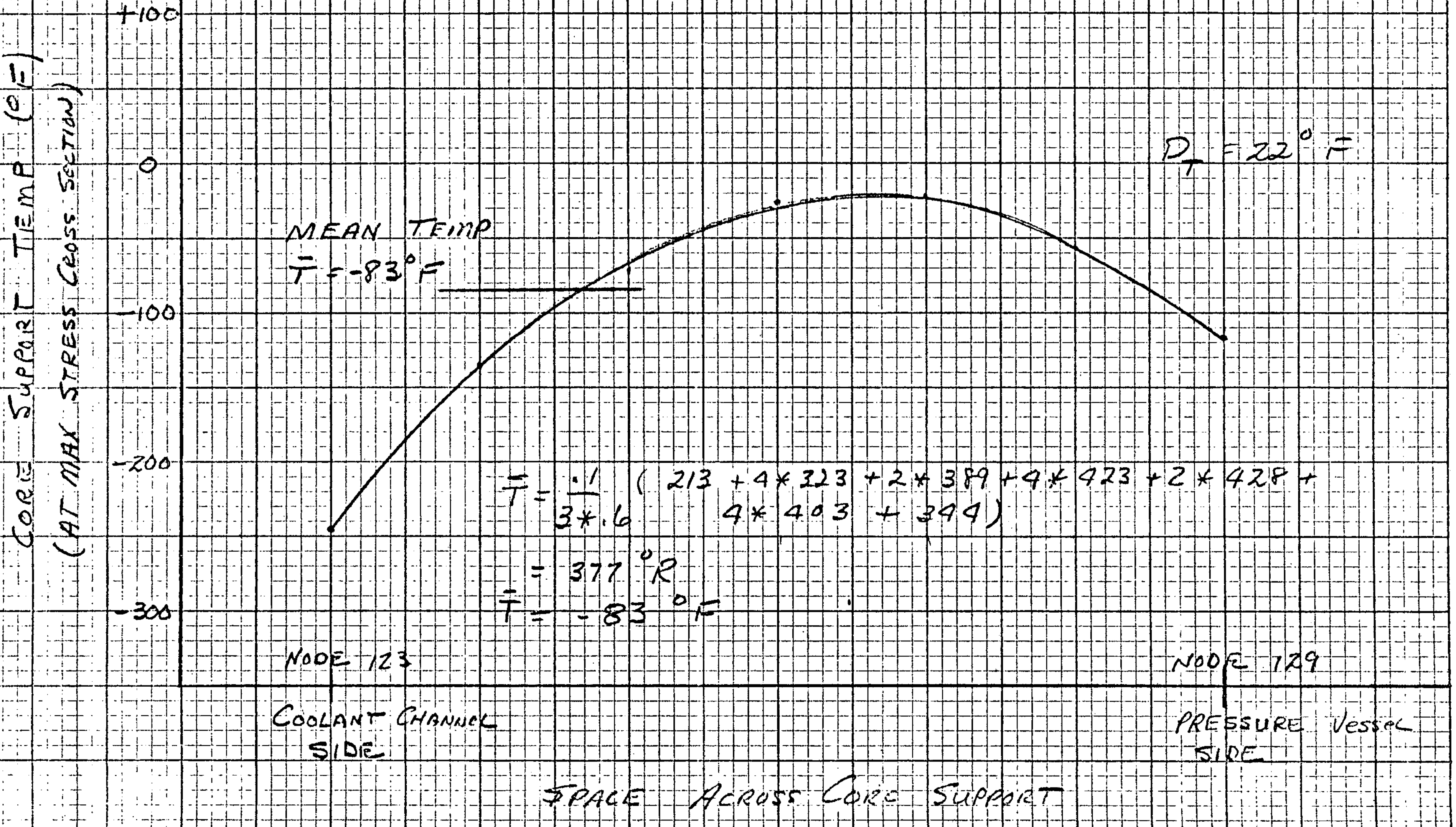
D_S DUE TO TEST VARIATION $= 6.6\ \bar{S} = 4950$ PSI.

D_S DUE TO TEMP VARIATION $= 3000$ PSI.
(DIFFERENCE BETWEEN STRENGTH AT
-83 AND AT $-61°F$)

TOTAL $D_S = \sqrt{4950^2 + 3000^2}$

$= 5788$ PSI.

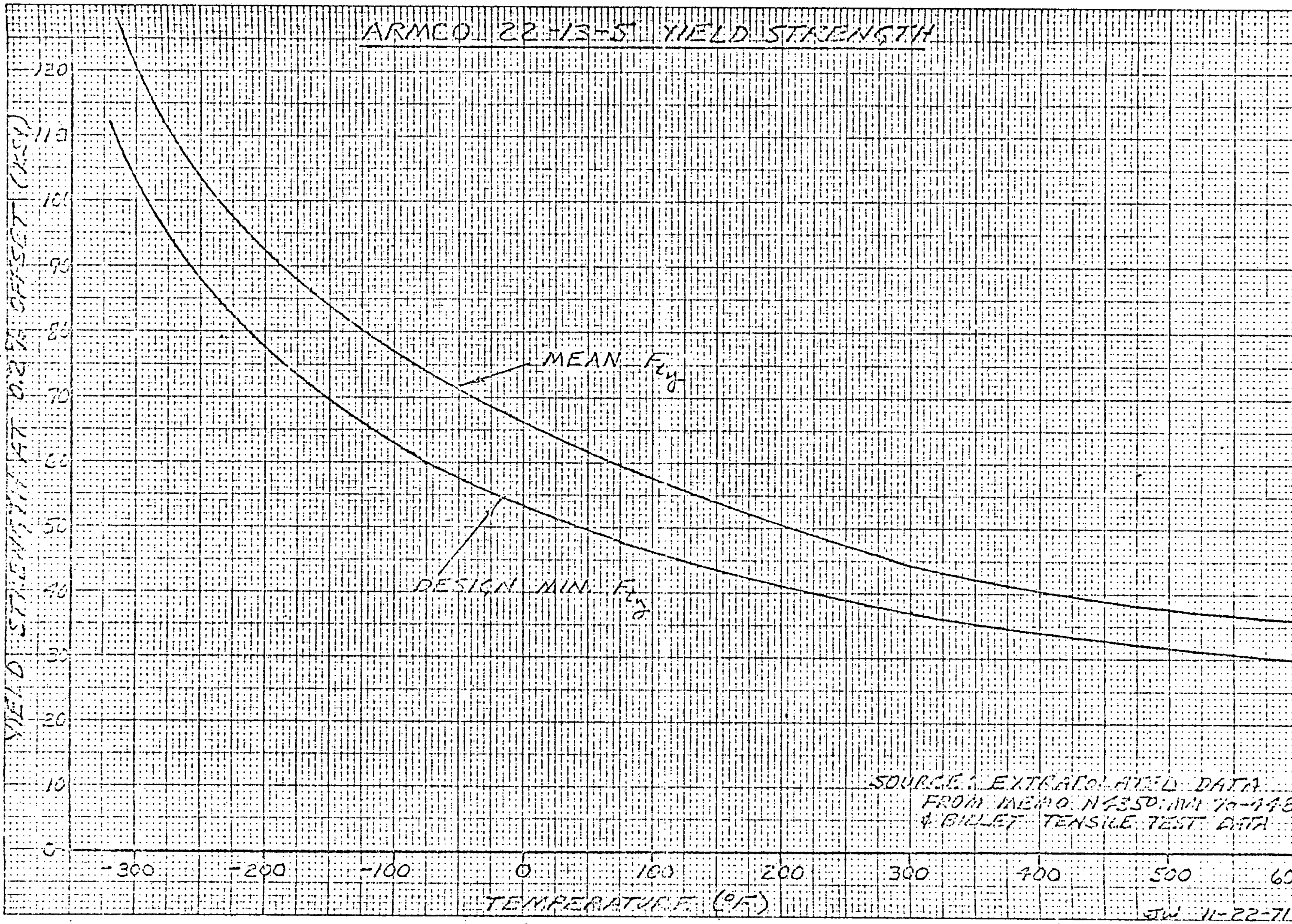
NOZZLE CORE SUPPORT TEMPERATURE
AT CROSS SECTION OF MAX STRESS.
REF RUN JOE 428237, 2, 100
23 FEB 1972



$$\bar{T} = \frac{.1}{3 * .6} \left(213 + 4*323 + 2*389 + 4*423 + 2*428 + 4*403 + 344 \right)$$

$$= 377°R$$

$$\bar{T} = -83°F$$



SECTION E

Enclosure (1)
N8500:MI432

2-6

AGCS-0800-11

SUBJECT	REPORT NO	PAGE 3 OF
CORE SUPPORT FMA VIII E CONTINUED		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 4/17/72

$$M.S. = \frac{.85 * 54000}{33,500} - 1$$

$$= +0.37$$

$$J = \frac{75,000 - 31,868}{\sqrt{5788^2 + 544^2}}$$

$$= 7.42$$

RELIABILITY $= .9_8 63$

RELIABILITY IS BELOW THE ALLOCATION OF $9_{10}8$. NEXT DETERMINE REDUCTION IN STRESS OR INCREASE IN STRENGTH REQUIRED TO ACHIVE ALLOCATION.

AGCS-0800-11

REPORT NO.	PAGE 4 OF

SUBJECT

Section E Continued..

DATE	WORK ORDER

BY	CHK. BY	DATE

```
SYSTEM- FØR                  KFB17963,II

NEW ØR ØLD--ØLD
ENTER FILE NAME-REL5:: DELETED
REL5**
READY
RUN

REL5**       09:49PST     04/19/72

TØLERANCE FACTØR...............?7.42

EQUIVALENT DEGREES ØF FREEDØM..?19.

SAMPLE SIZE FØR MEAN...........?20.

CØNFIDENCE LEVEL...............?0.90

            RESULTS------
   1 - RELIABILITY =                             0.36617248E-08
   INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =        5.78333390
```

= 9 63/8

APPENDIX F

RELIABILITY REPORT
ON NOZZLE COOLANT PASSAGE FAILURE MODES

N8500:72-R:023

ENGINEERING OPERATIONS REPORT

Reliability Analysis of the Nozzle Coolant Passage Failure Mode

Project 141

Work Statement No. 14

March 1972

R. G. Ackerman
Nozzle and Pressure Vessel Section

Approved:

L. A. Shurley, Manager
Nozzle Pressure Vessel and
Nozzle Extension Department

TABLE OF CONTENTS

I. INTRODUCTION

The NERVA nozzle performs two primary functions in the nuclear engine system. It must first contain and direct cool hydrogen from the inlet at the aft end (Figure 1) through coolant channels to the pressure vessel plenum. Secondly, it must contain and direct high temperature (4250°F) hydrogen expelled from the reactor core. This high temperature gas is accelerated as it passes through the nozzle throat until it reaches maximum velocity at the end of the nozzle extension. It is this high velocity gas that provides engine thrust.

A preliminary analysis was conducted to evaluate the coolant channel design as shown in the nozzle layout drawing P/N 1138000A, Reference (a). The first step in the analysis was to write a failure mode analysis which describes each potential failure mechanism in the nozzle assembly. The FMA also shows what independent variables affect the structural integrity of the failure mechanism. This FMA was transmitted to the SNSO-C by memorandum 7750:M1084, dated 30 September 1970 (Reference (b)).

The purpose of this report is to describe the results of the analysis conducted on Section VII of the FMA. This section describes the cold hydrogen containment section of the nozzle. All failure mechanisms combine to make one mode of failure called "Failure to Deliver the Required Amount of Propellant to Reflector Inlet." Seventeen failure mechanisms were described under this mode. Of these, 15 were calculated prior to contract termination. The remaining two mechanisms described joint leakage, and were in progress but incomplete. These two mechanisms (FMA VII L and P) will not be included in this report.

The reliability values shown in this report represent the state of development at time of the analysis was conducted, and should not be considered final. Most of the work was done in 1971, and in some cases additional thermal analysis was conducted at later dates and not included in the calculations. In addition, techniques were developed later which allowed temperature to be included as an independent variable. This was not done for the data included in this report, however, E25107 (Coolant Channel Temperature and Pressure Analysis Program) computer runs will be included in the data package backup.

The nozzle configuration described in this report is P/N 1138000A. Later modifications to this drawing changed the flange area but had no affect on the

C

calculations in the report. Armco 22-13-5 (Reference (c)) material was used for the jacket shell and manifolds. CRES 347 (Reference (d)) material was used for the coolant channels. The Armco 22-13-5 materials data was based on a very limited test program intended to provide preliminary information on the material. The materials data did not provide a statistical distribution; therefore, the standard deviation of yield strength was assumed to be 6.6% of the mean value. The CRES 347 materials data used for the analysis was Category A or B data which had sufficient test to provide statistical distributions.

The method of determining reliability is shown in NRP-411 (Reference (d)). This document describes how to find the stress distribution using the independent stress variables, and how to determine reliability once the stress and strength means and distributions are known.

The methods of analysis used for these calculations are based primarily on the propagation of various techniques and Monte Carlo techniques described in NRP-411. These techniques are used to find the statistical distribution about the mean stress value. The strength distribution is determined from materials test data, and combined with the stress distribution to find the reliability value. For this analysis, reliability is based on a material sample* size of 20, and a 90% confidence level.

II. SUMMARY AND CONCLUSIONS

The failure mode analysis which was written to identify the potential failure points in the NERVA nozzle contains six failure modes. The failure mode identified as "Failure to Deliver the Required Amount of Propellant to Reflector Inlet" is discussed in the report. This mode was broken down into 17 mechanisms, 14 of which are discussed in this report. Two mechanisms which described joint leakage were not completed.

The preliminary results of the analysis are summarized below, along with the allocated reliability of each mechanism. The allocation was arrived at by starting with the total nozzle reliability for each category of failure shown in Nozzle Specification EC 90196C, Pg. 49, Table VIII. This allocation was then broken into mechanism allocations for each category of failure using the formula:

* (1) CRES 347 material data reflect population sample ranging from 18 to 25.
(2) ARMCO 22-13-5 test plan (not executed due to termination) was structured to produce population sample of 20.

$$\text{FAILURE MECHANISM ALLOCATION} = 1 - \left(\frac{1 - \text{Total Component Allocation per Category}}{\text{Number of Failure Mechanism per Category}}\right)$$

This formula is shown in NRP-411, page

Preliminary results of the analysis are as follows:

FMA VII	Coolant Passages	Margin of Safety	Calculated Reliability	Reliability Allocation	Failure Category
A	Inlet Manifold	.186	$.9_{16}47$	$.9_{10}88$	IV
B	Inlet Elbow	2.97	$.9_{18}88$	$.9_{10}88$	IV
C	Elbow Weld	.82	$.9_{15}89$	$.9_{10}88$	IV
D	Tube Erosion	.26	$.9_{9}67$	$.9_{6}89$	III
E	Tube Rupture	.26	$.9_{11}58$	$.9_{10}88$	IV
F	Tube Buckling	.16	$.9_{7}8$	$.9_{6}89$	III
G	Tube Fatigue		$.9_{8}8$	$.9_{6}89$	III
H	Coolant Manifold	9.2	$.9_{23}$	$.9_{10}88$	IV
I	End Cap	3.0	$.9_{17}9$	$.9_{10}88$	IV
J	End Cap Braze (to Jacket)		$.9_{10}88$*	$.9_{10}88$	IV
K	End Cap Weld (to Jacket)		$.9_{11}$	$.9_{10}88$	IV
L	Bolt Seal Leak	calculations not complete			III
M	Jacket Rupture (Aft End)	1.46	$.9_{17}8$	$.9_{10}88$	IV
N	Tube Braze Joints		$.9_{10}88$**	$.9_{10}88$	IV
O	Inlet Manifold Weld	.80	$.9_{15}71$	$.9_{10}88$	IV
P	Nozzle/P.V. Seal Leak	calculations not complete			III
Q	Bolt Coolant Manifold Weld	3.08	$.9_{23}$	$.9_{10}88$	IV

*Assumes 30% engagement.

**Assumes 20% engagement.

It can be concluded that the coolant passage design is reliable and will perform within the specified limits without structural failure. This conclusion applies only to normal* operating conditions with a gas temperature of 4250°R. Calculations at other operating conditions have not been completed. The calculations use a 90% confidence level with an assumed sample size of 20 for stress and materials combined.

These reliability values are the result of a preliminary evaluation conducted to locate problem areas that may require redesign. To determine the final absolute reliability value of the nozzle, additional analysis must be conducted using stress and temperature values calculated by computer techniques. Some failure mechanisms show extremely high reliability, and a weight reduction may be possible.

These calculations are unchecked, therefore, the possibility of arithmetic error exists.

III. TECHNICAL DISCUSSION

Technical discussion will be written at a later date as time permits.

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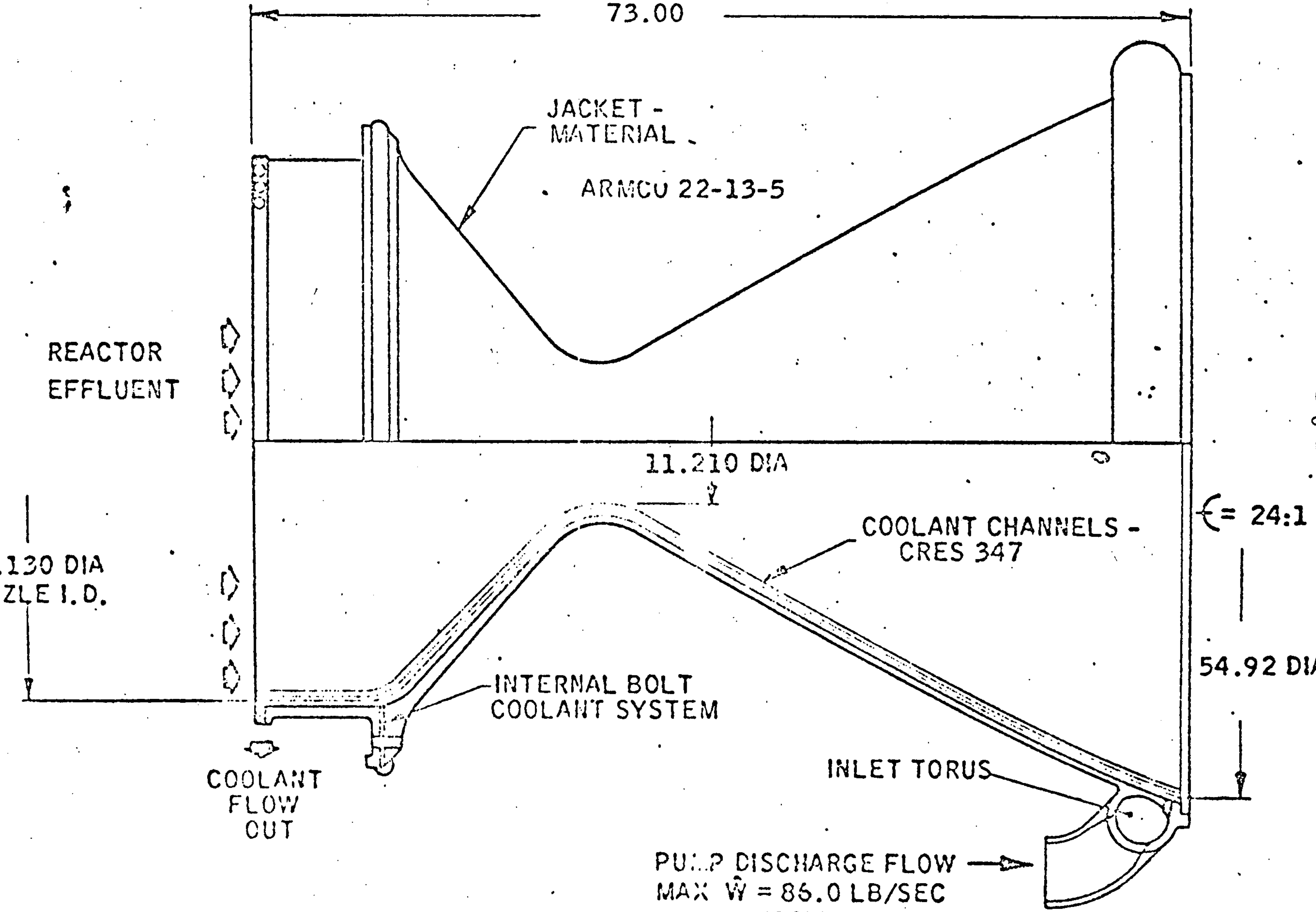
* Normal operating mode, End of Life, tends to induce more thermal severity as compared with normal start, shutdown, throttling, or Start of Life modes.

IV. RECOMMENDATIONS

The joint leakage mechanisms which describe leakage at the nozzle/P.V. seal, and at the bolt head seal should be calculated. Initial effort on these mechanisms used the theory of Paul Bower at IIT Research Institute. When this effort is completed, an overall preliminary reliability value for this failure mode can be calculated.

Additional analysis should be conducted using the finite element program to determine stress mean values and stress distributions. Thermal analysis should also be conducted to determine temperature means and distribution. The results of this work should then be used to calculate an updated reliability value for this mode.

NERVA CRYO COOLED NOZZLE



AEROJET NUCLEAR SYSTEMS COMPANY

V. REFERENCES

(a) ANSC Drawing 1138000B, Nozzle Layout

(b) ANSC Memo 7750:M1084, L. A. Shurley to G. F. Mader/J. H. Ramsthaler, dated 30 September 1970, Subj: "Project 141 Work Statement Item No. 20, Nozzle and Nozzle Assembly FMA"

(c) ANSC Memo N4350:MM70-448, H. W. Spaletta to J. L. Watkins, dated 22 December 1970, Subj: "Armco 22-13-5 Alloy Preliminary Screening Results"

(d) ANSC Data Release Memo 02.05, Revision 0, dated 12/17/70 AISI 347 Sheet

(e) ANSC Nerva Program Procedure, Number:R101-NRP-411, Revision A, dated 4 January 1971, Subj: "Techniques for Assessing Component Reliability During Preliminary Design"

(f) ANSC Memorandum N8200:M3041, J. H. Ramsthaler to A. D. Cornell, dated 4 August 1971, Subj: "NERVA Engine Reliability Allocations"

APPENDIX A

FAILURE MODE VII CALCULATIONS

FMA VII	Coolant Passages
A	Inlet Manifold
B	Inlet Elbow
C	Elbow Weld
D	Tube Erosion
E	Tube Rupture
F	Tube Buckling
G	Tube Fatigue
H	Coolant Manifold
I	End Cap
J	End Cap Braze
K	End Cap Weld
L	Bolt Seal Leak
M	Jacket Rupture
N	Tube Braze Joints
O	Inlet Manifold Weld
P	Nozzle/P.V. Seal Leak
Q	Bolt Coolant Manifold Weld

AGCS-0800-11

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REPORT NO.		PAGE 1 OF
SUBJECT FMA VII A INLET MANIFOLD		DATE
		WORK ORDER
BY R.A. Ackerman	CHK. BY	DATE 5-27-71

- ARMCO NOZZLE - FULL THRUST S.O.L.

STRESS IN THE INLET TORUS CONSISTS OF HOOP MEMBRANE STRESS DUE TO LIQUID PRESSURE, THERMAL STRESS DUE TO THE ΔT ACROSS THE TORRUS WALL, AND BENDING STRESS DUE TO THE ΔT BETWEEN THE LOWER FLANGE AND THE UPPER JACKET.

THE HOOP STRESS AND TORUS WALL ΔT STRESS WILL BE CALCULATED HERE. THE STRESS DUE TO JACKET TO FLANGE ΔT WILL BE CALCULATED WHEN AN ASSESSMENT OF FLANGE TEMPERATURE CAN BE COMPLETED.

THE TORUS WALL THERMAL STRESS IS COMPRESSIVE ON THE OD, AND TENSILE ON THE ID AS SHOWN ON THE FOLLOWING SKETCH. THEREFORE THE NET STRESS IS NEAR ZERO THE CALCULATION IS NECESSARY HOWEVER TO DETERMINE THE AMOUNT OF CYCLIC FATIGUE THAT MAY OCCUR.

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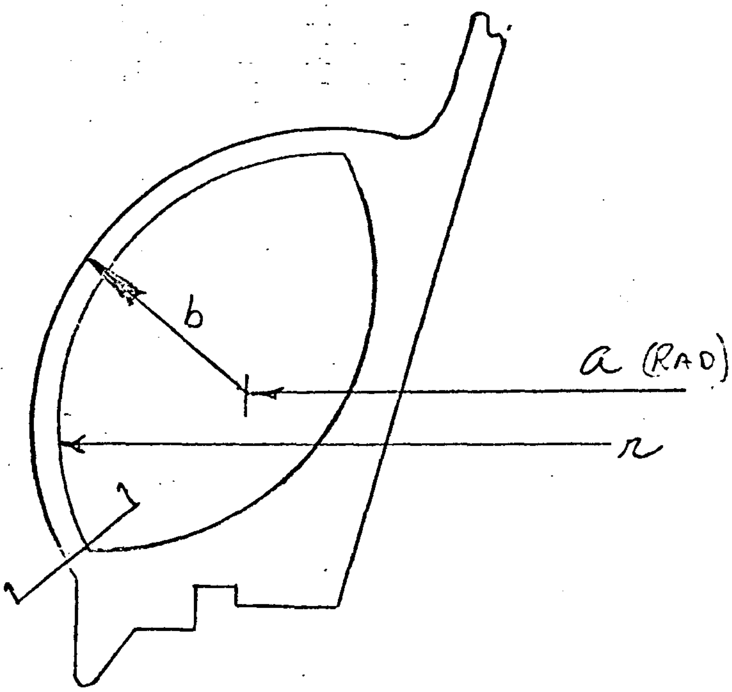
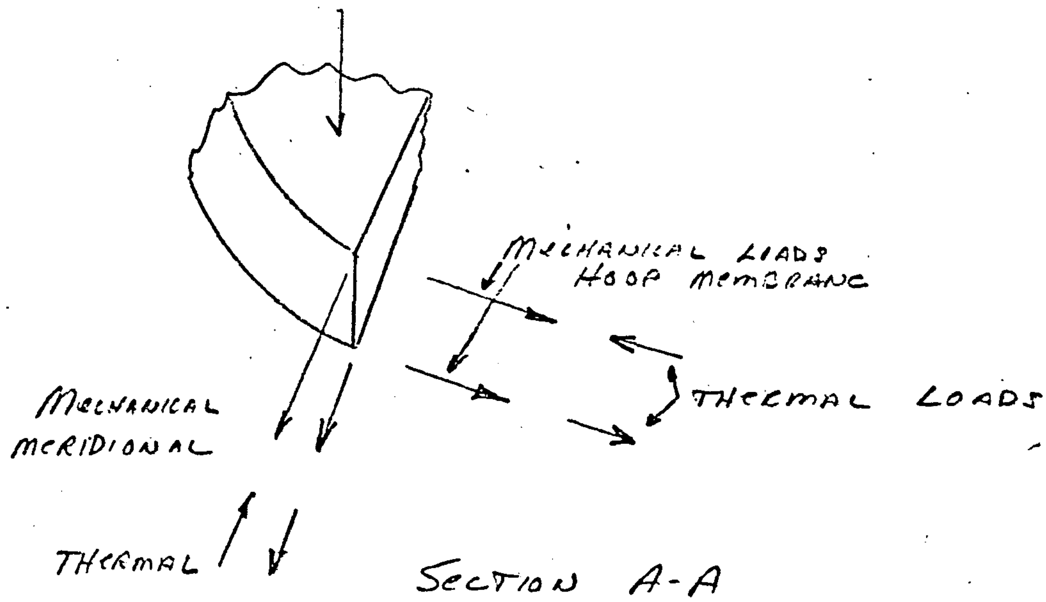
REPORT NO.	PAGE 2 OF
SUBJECT: SECTION A CONTINUED	DATE
	WORK ORDER
BY: RGA / CHK. BY	DATE 5-27-71





SECTION A-A

FIG 1

MATERIAL PROPERTIES:

MEAN WALL TEMP AT CROSSSECTION A-A

$T = -125^\circ F \pm 15\% \ (3\sigma)$

PER RUN NOBE 008 RLB

$T_{MAX} = -106^\circ F$

* $\bar{S} = 68{,}000$ PSI.

* $S_{MAX} = 52{,}000$ PSI.

* $D_S = 5330$ PSI.

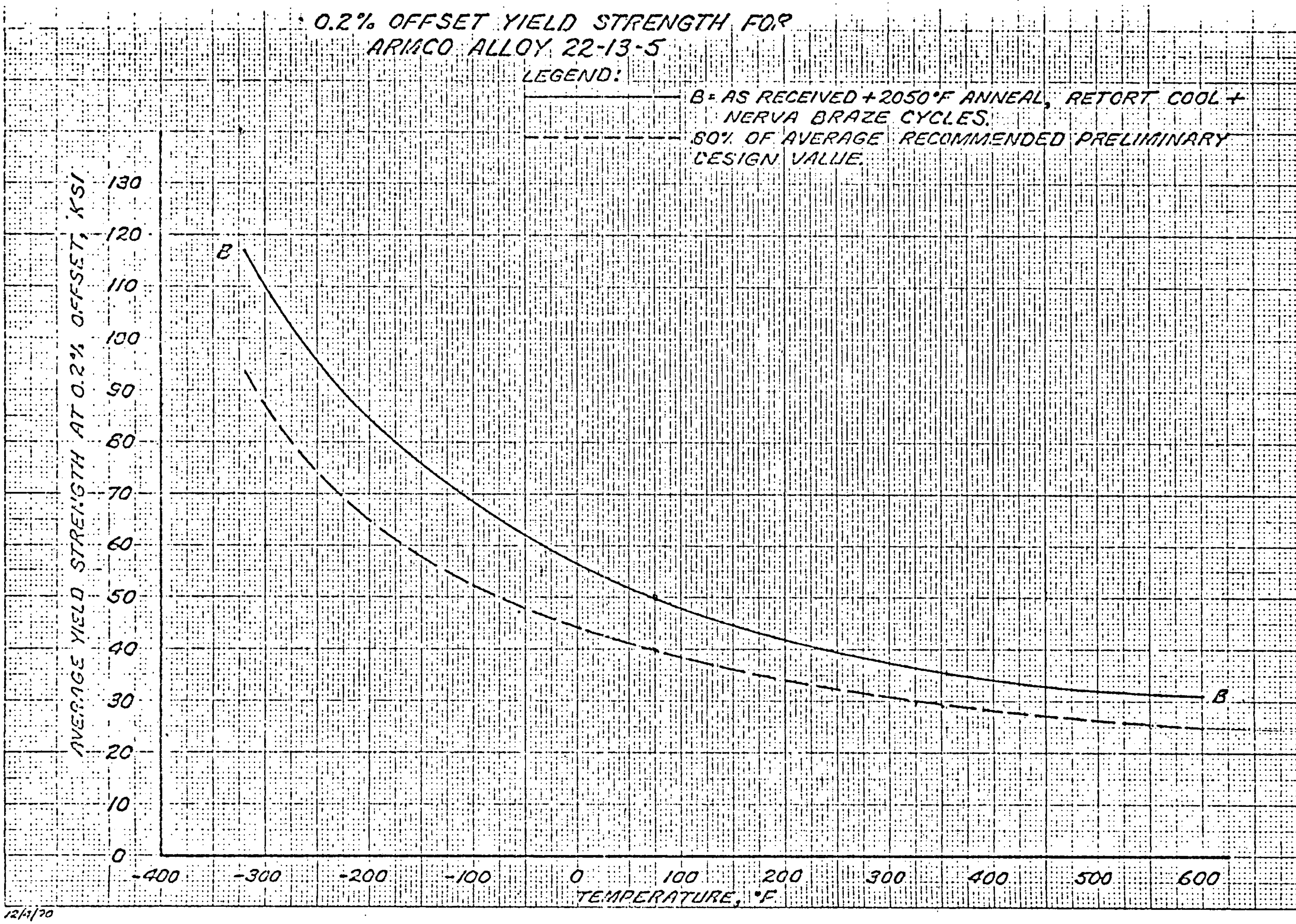
$V_E = 5\%$ $E = 30 \times 10^6$ $D_E = .9 \times 10^6$

$V_\alpha = 5\%$ $\alpha = 8.5 \ 10^{-6}$ AT $-100°F$ $D_\alpha = .85 \times 10^{-6}$

*MATERIAL PROPERTIES PER ARMCO SCREENING PROGRAM: MEMO: N 4350 MM 70-448 22 DEC 70. DESIGN STRENGTH (S_{MAX}) IS 80% OF MEAN STRENGTH.

VARIANCE $D_S = (\bar{S} - S_{MAX})/3$.

Fig 2



SECTION A

CALCULATE HOOP STRESS FOR THE FOLLOWING PARAMETERS. SEE SKETCH FOR DIMENSION DEFINITIONS.

P_{IN} =	1359 ± 56 PSI.	DRS 187 A (19)
b =	2.464 ± .030 IN	1138000 (A)
a =	28.82 ± .030	"
t =	.188 ± .010	"
r =	30.25 ± .030	"

STRESS $\bar{s} = \dfrac{Pb}{t}\left(\dfrac{r+a}{2r}\right)$ FOR TORUS.

$$\bar{s} = \frac{1359 * 2.464}{.188}\left(\frac{30.25 + 28.82}{2 * 30.25}\right)$$

$$\bar{s} = 17{,}390$$

SECTION A CONTINUED

$$D_s^2 = \left[\frac{P}{\tau}\left(\frac{r+a}{2r}\right) D_b\right]^2 + \left[\frac{b}{\tau}\left(\frac{r+a}{2r}\right) D_P\right]^2 + \left[\frac{P_b}{\tau^2}\left(\frac{r+a}{2r}\right) D_\tau\right]^2$$

$$+ \left[\frac{Pb}{\tau}\left(\frac{r}{2r}\right) Da\right]^2 + \left[\frac{Pb}{\tau} * \frac{a}{r^2} D_r\right]^2$$

$$= \left(\frac{1359}{.188} * .98 * .010\right)^2 + \left(\frac{2.469}{.188} * .98 * 18\right)^2$$

$$+ \left(\frac{1359 * 2.469 * .0033 * .98}{.188^2}\right)^2 + \left(\frac{1359 * 2.469}{.188} * \frac{30.25}{60.5} * .01\right.$$

$$+ \left(\frac{1359 * 2.469}{.188} * \frac{28.82}{30.69^2} * .010\right)^2$$

$D_s = 430$

SUBJECT: SECTION A CONTINUED

DATE

WORK ORDER

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MARGIN OF SAFTY DUE TO HOOP STRESS ONLY.

$$M.S. = \left[\frac{(52{,}000 - 3 * 5330) .85}{17{,}390 + 3 * 430}\right] - 1$$

$$M.S. = .638$$

CALCULATE THERMAL STRESS AT SECTION A-A
FIG 1 PAGE 2

ΔT AT SECTION AA IS $243° \pm 25° F$

$$\bar{\sigma}_{THERMAL} = \frac{E \alpha \Delta T}{2(1-\nu)}$$

$$= \frac{30 \times 10^{6} * 8.5 \times 10^{-6} * 243}{2(1 - .28)}$$

$$= 43{,}031 \text{ PSI}.$$

D

ASSUME $E, \alpha,$ AND ΔT ARE VARIABLES - ν IS A CONSTANT.

$$D_\sigma^2 = \left(\frac{E\alpha}{2(1-\nu)} D_{\Delta T}\right)^2 + \left(\frac{E\,\Delta T}{2(1-\nu)} D_\alpha\right)^2 + \left(\frac{\alpha\,\Delta T}{2(1-\nu)} D_E\right)^2$$

$$D_{\Delta T} = 8^\circ$$

$$D_\alpha = .85 * 10^{-6} \qquad (8.5 * 10^{-6}) * 10\%$$

$$D_E = .9 * 10^6 \qquad (30 * 10^6) * 3\%.$$

$$D_{\sigma\,THERM}^2 = \left(\frac{30 * 10^6 * 8.5 * 10^{-6}}{1.49} * 8\right)^2 + \left(\frac{30 * 10^6 * 243 * .85 * 10^{-6}}{1.44}\right)^2$$

$$+ \left(\frac{8.5 * 10^{-6} * 243 * .9 * 10^6}{1.44}\right)^2$$

$$D_{\sigma\,THERM} = 4710 \text{ PSI}.$$

STRESS AT THE OUTSIDE SECTION

$$\bar{\sigma}_T = \bar{\sigma}_{HOOP} + \bar{\sigma}_{THERM}$$

$$= 17,390 + 43031$$

$$\bar{\sigma}_T = 60,421 \text{ PSI.}$$

SINCE THE NET THERMAL STRESS IS ZERO, THIS IS CONSIDERED A SECONDARY STRESS PER SNPO-C-1 TABLE 1. THE ALLOWABLE STRESS FOR THIS CONDITION IS 2 F_y

$$\therefore \quad F_y = \bar{S}$$

$$\bar{S} = 2 * 68,000 = 136,000 \text{ PSI} = \text{MEAN STRENGTH}$$

$$S_{MAX} = 2 * 52,000 = 104,000 \text{ PSI.}$$

$$D_S = 5330 \text{ PSI.}$$

SUBJECT

SECTION A CONTINUED

DATE

WORK ORDER

BY RGA

CHK. BY

DATE 5-27-71

$$MS = \left(\frac{109{,}000 * .85}{60{,}421 + 3 * 4710} \right) - 1$$

$$M.S. = +.186$$

RELIABILITY

$$J = \frac{136{,}000 - 60{,}421}{\sqrt{5330^2 + 4710^2}}$$

$$= 10.62$$

RELIABILITY IS $.9_{16}47$

MONTE CARLO & SENSITIVITY ANALYSIS PROGRAM

Section A

10

IS THIS A MONTE CARLO OR SENSITIVITY ANALYSIS?
(ANSWER 'MONTE' OR 'SENS')?MONTE

DO YOU WANT TO USE STORED DATA FROM YOUR DATA-FILE?
(ANSWER 'YES' OR 'NO')?YES
FILE NAME, PLEASE?ACK

---------- RESULTS FOR 100 MONTE CARLO TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
STRS	0.6042E+05	0.5987E+05	4686.	0.7085E+05	0.4655E+05
DIFF	0.7558E+05	0.7562E+05	7272.	0.9117E+05	0.5550E+05

DO YOU WANT MORE MONTE CARLO TRIALS? YES
HOW MANY ADDITIONAL TRIALS (RESULTS ARE CUMULATIVE)? 500

---------- RESULTS FOR 600 MONTE CARLO TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
STRS	0.6042E+05	0.6024E+05	4649.	0.7353E+05	0.4419E+05
DIFF	0.7558E+05	0.7545E+05	6959.	0.9450E+05	0.5415E+05

DO YOU WANT MORE MONTE CARLO TRIALS? NO

---------- RESULTS FOR VARIABLE STRS----------

	TABULAR HISTOGRAM			TEST FOR NORMAL		
VALUE	SIGMA	FREQ	CUM	CUM PROB	EXPECTED	DIFF.
45045.8818	-3.27	1	1	0.001667	0.000541	0.001125
50522.5713	-2.09	9	10	0.016667	0.018305	0.001638
55999.2607	-0.91	95	105	0.175000	0.180885	0.005885
61475.9502	0.27	259	364	0.606667	0.604919	0.001748
66952.6396	1.44	193	557	0.928333	0.925659	0.002675
72429.3291	2.62	40	597	0.995000	0.995633	0.000633
HIGH END TAILS		3	600			

MAX DIFF. =0.005885

RELIABILITY ESTIMATED FROM SUCCESSES/POPULATION......R=1.0000000000
RELIABILITY ESTIMATED FROM LEAST SQUARES CURVE-FIT...R=0.9999999998 .998
FROM THE 20 VALUES NEAREST ZERO, BELOW

0.541526E+05	0.555003E+05	0.560013E+05	0.566354E+05	0.570622E+05
0.586431E+05	0.593100E+05	0.595094E+05	0.602831E+05	0.604925E+05
0.607696E+05	0.612087E+05	0.614459E+05	0.618899E+05	0.620965E+05
0.622352E+05	0.622483E+05	0.625526E+05	0.625701E+05	0.627980E+05

CRITICAL DIFFERENCES — LEVEL OF SIGNIFICANCE
(N GREATER THAN 50) --

20%	15%	10%	5%	1%

```
READY
EDIT $FI /STRS  NO    NO       0/ $RE /STRS  NO    YES      5/ SEND
```

SECTION A

11

```
READY
LIST ACK

ACK           09:11 L      06/02/71

        100           201          10             0            2          20
          1             2   1.3590000E+03   1.8000000E+01   0.
          2             2   2.4640000E+00   1.0000000E-02   0.
          3             2   2.8320000E+01   1.0000000E-02   0.
          4             2   1.5800000E-01   3.3000000E-03   0.
          5             2   3.0250000E+01   1.0000000E-02   0.
          6             2   3.0000000E+07   9.0000000E+05   0.
          7             2   2.4300000E+02   8.0000000E+00   0.
          8             2   8.5000000E-06   8.5000000E-07   0.
          9             2   2.8000000E-01   1.0000000E-03   0.
         10             2   1.3600000E+05   5.3300000E+03   0.
   1  STRS  NO    NO       0  NO    0.                  NO    0.
   2  DIFF  YES   NO       0  NO    0.                  NO    0.


READY
EDIT FI DELETED
EDIT $FI /NO    NO       0/ $RE /NO     YES       5/SEND

-NO STRING ON FIND-

-INSERT/REPLACE NOT PRECEEDED BY FIND-

READY
OLD ACK
READY
EDIT $FI /STRS  NO    NO       0/ $RE /STRS  NO    YES      5/ SEND

READY
REPLACE
READY
LIST ACK
```



```
ACK           09:17 L      06/02/71

        100           201          10             0            2          20
          1             2   1.3590000E+03   1.8000000E+01   0.
          2             2   2.4640000E+00   1.0000000E-02   0.
          3             2   2.8320000E+01   1.0000000E-02   0.
          4             2   1.3300000E-01   3.3000000E-03   0.
          5             2   3.0250000E+01   1.0000000E-02   0.
          6             2   3.0000000E+07   9.0000000E+05   0.
          7             2   2.4300000E+02   8.0000000E+00   0.
          8             2   8.5000000E-06   8.5000000E-07   0.
          9             2   2.8000000E-01   1.0000000E-03   0.
         10             2   1.3600000E+05   5.3300000E+03   0.
   1  STRS  NO    YES      5  NO    0.                  NO    0.
   2  DIFF  YES   NO       0  NO    0.                  NO    0.


READY
OLD I3RUS
READY
COMPILE
```

MØNTE CARLØ & SENSITIVITY ANALYSIS PRØGRAM

Section A

12

IS THIS A MØNTE CARLØ ØR SENSITIVITY ANALYSIS?
(ANSWER 'MØNTE' ØR 'SENS')?MØNTE

DØ YØU WANT TØ USE STØRED DATA FRØM YØUR DATA-FILE?
(ANSWER 'YES' ØR 'NØ')?YES
FILE NAME, PLEASE?ACK

---------- RESULTS FØR 100 MØNTE CARLØ TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
STRS	0.6042E+05	0.5987E+05	4686.	0.7085E+05	0.4655E+05
DIFF	0.7558E+05	0.7562E+05	7272.	0.9117E+05	0.5550E+05

DØ YØU WANT MØRE MØNTE CARLØ TRIALS?NØ

---------- RESULTS FØR VARIABLE STRS----------

	TABULAR HISTØGRAM				TEST FØR NØRMAL	
VALUE	SIGMA	FREQ	CUM	CUM PRØB	EXPECTED	DIFF.
45045.8818	-3.16	0	0	0.	0.000780	0.000780
50522.5713	-1.99	1	1	0.010000	0.023057	0.013057
55999.2607	-0.83	20	21	0.210000	0.204542	0.005458
61475.9502	0.34	38	59	0.590000	0.634325	0.044325
66952.6396	1.51	36	95	0.950000	0.934755	0.015245
72429.3291	2.68	5	100	1.000000	0.996330	0.003670
HIGH END TAILS		0	100			

MAX DIFF. =0.044325

For Sample Size=10[illegible]

RELIABILITY ESTIMATED FRØM SUCCESSES/PØPULATIØN......R=1.0000000000
RELIABILITY ESTIMATED FRØM LEAST SQUARES CURVE-FIT...R=0.9999995166 *0.57*
FRØM THE 20 VALUES NEAREST ZERØ, BELØW

0.555003E+05	0.570622E+05	0.595094E+05	0.622352E+05	0.625701E+05
0.636266E+05	0.659985E+05	0.662934E+05	0.673722E+05	0.677391E+05
0.679253E+05	0.680531E+05	0.684646E+05	0.684824E+05	0.689754E+05
0.691479E+05	0.691753E+05	0.693353E+05	0.700927E+05	0.705765E+05

CRITICAL DIFFERENCES (N GREATER THAN 50)	LEVEL OF SIGNIFICANCE				
	20%	15%	10%	5%	1%
	0.1070	0.1140	0.1220	0.1360	0.1630

PRØGRAM STØP AT 496

USED 4.69 UNITS

SUBJECT FMA VII B INLET ELBOW.

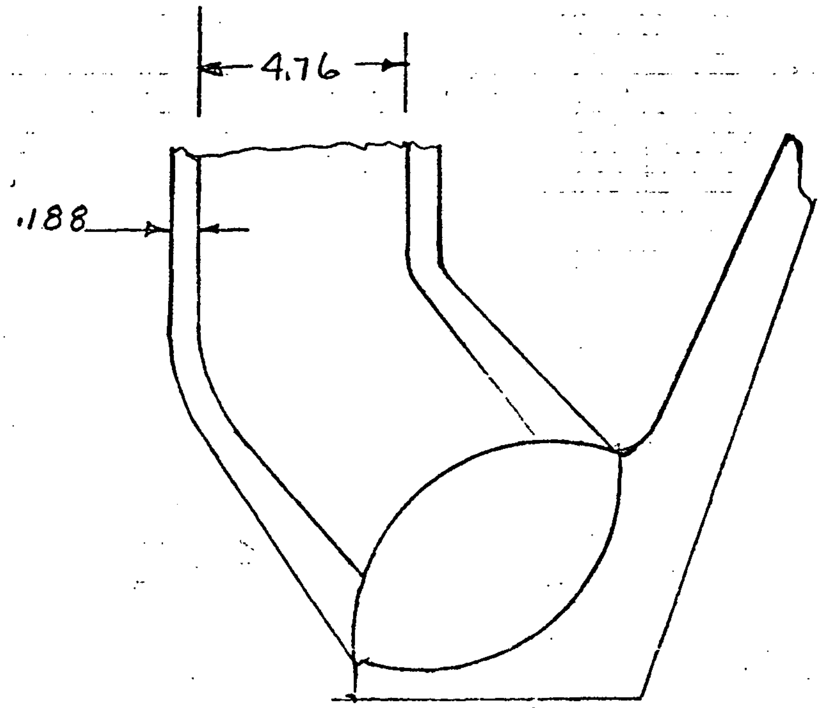
DATE

WORK ORDER

BY R.B. Ackerman

CHK. BY

DATE 6-3-71



RELIABILITY OF INLET ELBOW DUE TO PRESSURE LOADS.

FULL THRUST 50L

INLET PRESSURE P_{IN} = 1359 PSG DES 1E7AH

INLET RADIUS R = 2.474 ± .030 1138000

INLET THICKNESS τ = .188 ± .010 "

SUBJECT

SECTION B CONTINUED

DATE

WORK ORDER

BY

CHK. BY

DATE 6-3-71

MATERIAL PROPERTIES. —
BASED ON ARMCO SCREENING PROGRAM
MEMO 4350: MM 70-448 22 DEC 1970

TEMP = −300 °F ESTIMATED BASED ON T_1

$\bar{S} = 110{,}000$ PSI.

$S_{DES} = 86{,}000$ PSI.

$$D_S = (110{,}000 - 86{,}000)/3$$
$$= 8000$$

$$\bar{\sigma} = \bar{P}\bar{R}/\bar{t} = 1359 * 2.38 / .188$$
$$= 17{,}204$$

$$D_\sigma^2 = \left(\frac{R}{t} D_P\right)^2 + \left(\frac{P}{t} D_R\right)^2 + \left(-\frac{PR}{t^2} D_t\right)^2$$

$$= \left(\frac{2.38}{.188} * 19\right)^2 + \left(\frac{1359}{.188}\ .010\right)^2 + \left(\frac{1359 * 2.38}{.188^2} * .0033\right)^2$$

$$= 393$$

SUBJECT

FMA VII B CONTINUED

DATE

WORK ORDER

BY R. D. Ackerman

CHK. BY

DATE 6-3-71

$$M.S. = \left(\frac{.85 * 86{,}000}{17204 + 3 * 393} \right) - 1$$

$$M.S. = 2.97$$

RELIABILITY

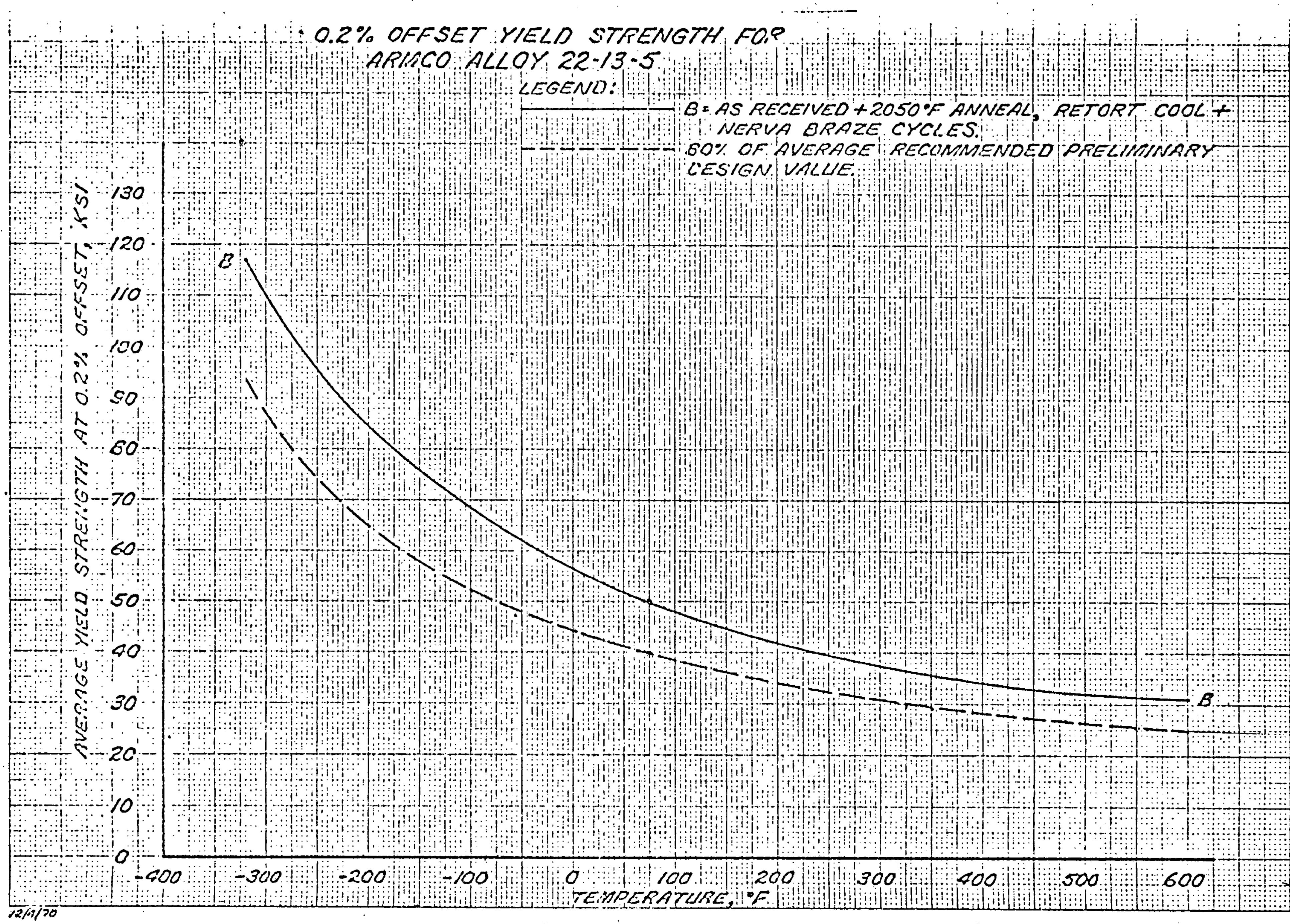
$$J = \frac{110{,}000 - 17204}{\sqrt{8000^2 + 393^2}}$$

$$= 11.5$$

RELIABILITY ~~7.9s~~ = 9₁₈ 88

MONTE CARLO NOT RQD DUE TO HIGH M.S. AND REL.

Fig 2



Section 13.4

Fig. 2

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SUBJECT FMA VII B INLET ELBOW.		DATE
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BY R.B. Ackerman	CHK. BY	DATE 6-3-71

THE INLET ELBOW HAS VERY HIGH RELIABILITY WHEN ONLY HOOP STRESS IS CONSIDERED.

THE MATERIAL THICKNESS SHOULD NOT BE REDUCED AT THIS TIME HOWEVER BECAUSE THE BENDING AND THERMAL LOADS AT THE ELBOW TO TORUS WELD ARE NOT KNOWN.

RECOMMEND LEAVING DESIGN AS IS UNTIL ADDITIONAL STRESS ANALYSIS CAN BE COMPLETED.

AEROJET-GENERAL CORPORATION
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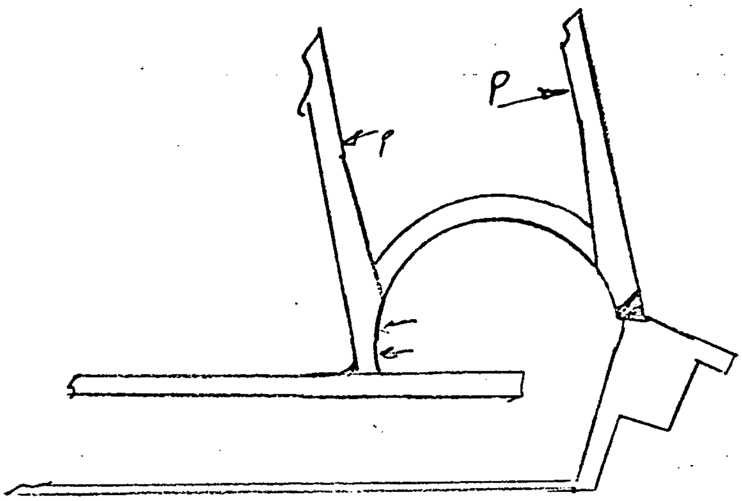
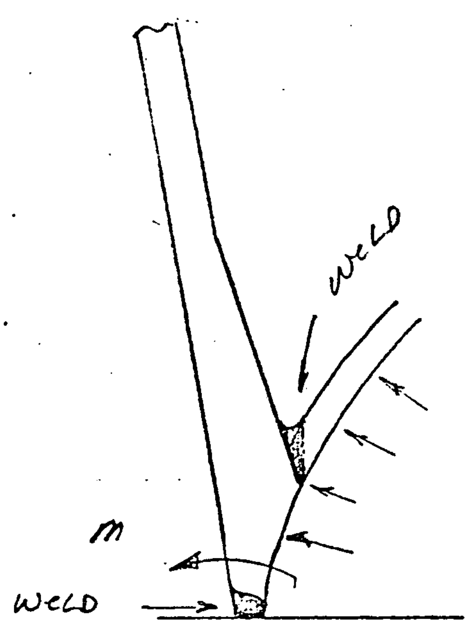
AGCS-0800-11

SUBJECT: FMA VII C MANIFOLD INLET TO MANIFOLD WELD JOINT.		DATE:
		WORK ORDER:
BY: R. G. Ackerman	CHK. BY:	DATE: 7-14-71

REPORT NO.





SUBJECT

SECTION C CONTINUED

DATE

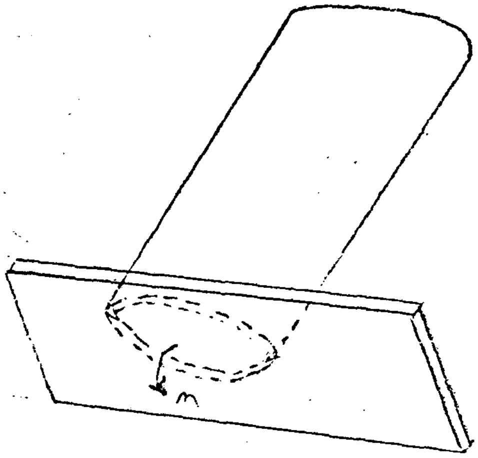
WORK ORDER

BY R.D. Ackerman

CHK. BY

DATE 7-14-71

MODEL: ASSUME THE INLET IS A CYLINDER WELDED TO A FIXED SURFACE AS SHOWN.



USE CYLINDER DEFORMATION EQUATIONS TO DEVELOP MOMENT. SLOPE EQUATIONS ARE WRITTEN IN TERMS OF DEFLECTION & MOMENT, AND SOLVED FOR MOMENT.

TERMS;

Θ = SLOPE OF CYLINDER WALL

M_0 = MOMENT

P_0 = FORCE

$\beta = 1.285/\sqrt{rt}$

r = RADIUS

t = THICKNESS

ν = POSSION'S RATIO

p = PRESSURE

$k = ET/r^2$

$C_{\beta x}$, $D_{\beta x}$ DISTANCE LOCATION = 1 AT WELD JOINT.

SUBSCRIPTS C = CYLINDER
H = HEAD OR RIGID PLATE.

SLOPE

$$\Theta_{HP_0} - \Theta_{HM_0} = \Theta_{CM_0} - \Theta_{CP_0}$$

SLOPE OF THE PLATE = 0 SINCE IT IS RIGID.

$$\therefore \Theta_{CM_0} = \Theta_{CP_0}$$

EQU 1 $$\Theta_{CM_0} = \frac{4 M_0 \beta^3}{k} D_{\beta x} \qquad \Theta_{CP_0} = \frac{2 P_0 \beta^2}{k} H_{\beta x}$$

$$\therefore \frac{4 M_0 \beta^3}{k} D_{\beta x} = \frac{2 P_0 \beta^2}{k} A_{\beta x}$$

E

DISPLACEMENT. (δ)

$$\delta = \delta_{c_{P_0 m_0}}$$

$$\delta = \frac{p r^2}{2 \tau E}(1-\nu)$$

$$\delta_{c_{P_0 m_0}} = \frac{2 P_0 \beta}{k} D_{\beta x} - \frac{2 M_0 \beta^2}{k} C_{\beta x}$$

EQU 2 $\quad \dfrac{p r^2}{2 \tau E}(2-\nu) = \dfrac{2 P_0 \beta}{k} D_{\beta x} - \dfrac{2 M_0 \beta^2}{k} C_{\beta x}$

SOLVE EQUATIONS 1 & 2 FOR M_0

$$M_0 = \frac{p(2-\nu)}{4\beta^2} = \frac{p r \tau (2-\nu)}{6.605}$$

BENDING STRESS $= \dfrac{6 M_0}{\tau^2} = s_B$

$$s_B = \frac{.908\, p r (2-\nu)}{\tau}$$

SUBJECT

SECTION C CONTINUED

BY RGA

CHK. BY

DATE 7-14-71

$\beta = 1359$ $\qquad D_\beta = 18$

$r = 2.38$ $\qquad D_r = .01$

$\tau = .188$ $\qquad D_\tau = .0033$

$\nu = .29$ $\qquad D_\nu = .01$

$$s_\beta = \frac{.908 * 1359 * 2 - .29 * 2.38}{.188}$$

$$= 26600 \text{ psi.}$$

$$D_{s_\beta}^2 = \left(\frac{\partial s}{\partial \beta} D_\beta\right)^2 + \left(\frac{\partial s}{\partial \nu} D_\nu\right)^2 + \left(\frac{\partial s}{\partial r} D_r\right)^2 + \left(\frac{\partial s}{\partial \tau} D_\tau\right)^2$$

$$= \left(\frac{.908 * (2-\nu) * r * D_\beta}{\tau}\right)^2 + \left(\frac{.908\, r \beta\, D_\nu}{\tau}\right)^2$$

$$+ \left(\frac{.908\, \beta\, (2-\nu)\, D_r}{\tau}\right)^2 + \left(\frac{.908\, \beta\, (2-\nu)\, r\, D_\tau}{\tau^2}\right)^2$$

$$D_{s_\beta} = 616 \text{ psi.}$$

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SUBJECT: SECTION C CONTINUED		DATE
		WORK ORDER
BY: RGA	CHK. BY	DATE 7/14/70

MATERIAL PROPERTIES.

NO THERMAL ANALYSIS EXHISTS AT THIS TIME FOR THE AREA AT THE INLET WELD, HOWEVER, THE TEMPERATURE SHOULD BE SIMILAR TO THE TEMP OF THE MANIFOLD TO JACKET WELD THAT TEMP WILL BE USED.

$\bar{T} = -322°F$ Ref Memo F110:M1710 18 JUNE 1971.

ARMCO PROPERTIES:

$\bar{S} = 110{,}000$ Psi. Ref 4350: MM 70-448

$S_{Des} = 87{,}000$ Psi. "

$D_S = 7666$ Psi. "

$\bar{B}_{YK} = 125{,}000$ Psi. PER SNPO-C-1 APP II

$B_{YK_{Des}} = 108{,}000$ Psi.

HOOP STRESS FROM FMA VII B

$\bar{\Delta} = 17{,}204$

$D_\Delta = 393$

SUBJECT

SECTION C CONTINUED

BY R.D. Ackerman

CHK. BY

DATE 7-14-71

TOTAL STRESS

$$\bar{s}_T = \bar{s}_H + \bar{s}_B$$

$$= 17{,}204 + 26{,}600 \text{ PSI.}$$

$$\bar{s}_T = 43{,}804$$

$$D_{s_T} = D_{s_H} + D_{s_B}$$

$$= 393 + 616$$

$$D_{s_T} = 1009 \text{ PSI.}$$

$$MS = \frac{.85 * S_{DES}}{s_T + 3\ D_s} - 1$$

$$= \frac{.85 * 100{,}000}{43{,}804 + 3 * 1009} - 1$$

$$M.S. = .815$$

RELIABILITY

$$J = \frac{\bar{S} - \bar{A}}{\sqrt{D_S^2 + D_{AT}^2}}$$

$$J = \frac{125{,}000 - 43{,}804}{\sqrt{7666^2 + 1009^2}}$$

$$J = 10.5$$

RELIABILITY $> . \cancel{9_9 5}$ $= 9_{15}\,89$

CONCLUSION: THE CLOSED FORM SHELL AND PLATE MODEL USED FOR THIS ANALYSIS MUST BE CONSIDERED AN APPROXIMATION BECAUSE OF THE CURVED CONFIGURATION OF THE ELBOW AND TORUS. TRUE STRESS SHOULD BE COMPUTED WITH THE FINITE ELEMENT COMPUTER PROGRAM WHEN TIME PERMITS. THE ABOVE ANALYSIS SHOULD HOWEVER BE CONSERVATIVE BECAUSE IT DOES NOT CONSIDER THE COMPOUND CURVATURE OF THE WELD.

AGCS-0800-11

REPORT NO.

PAGE 1 OF

SUBJECT: COOLANT TUBE EROSION FMA VII D

DATE

WORK ORDER

BY: R.D. Ackerman

CHK. BY

DATE 5/15/72

COOLANT TUBE EROSION BEGINS WHEN THE TUBE MATERIAL BECOMES SOFT ENOUGH TO ALLOW THE HOT GAS TO DISLODGE SURFACE MOLOCULES. THE EXACT TEMPERATURE AT WHICH THIS OCCURRS IS UNKNOWN, HOWEVER TUBE MELTING BEGINS AT APPROXIMATELY 2100°F MAXIMUM, AND 1950°F MINIMUM.

ASUME THE MEAN EROSION POINT ($\bar{T}_E$) IS:

$$\bar{T}_E = \frac{2100 + 1950}{2} = 2025\,^\circ F$$

VARIATION WILL BE $\frac{2100 - 2025}{3} = 25\,^\circ F$

SUBJECT Sec D Continued.

DATE

WORK ORDER

BY R.G.A. CHK. BY DATE 5/15/72

THE NOZZLE TUBES REACH A MAXIMUM TEMP AT STATION 22 DURING FULL POWER AT NORMAL OP. EOL. (Ref COMPUTER RUN 0956005

$\overline{T}_{wg} = 1471°F$

$D_{Twg} = 34°$ ASSUMED.

$$J = \frac{2025 - 1471}{\sqrt{25^2 + 34^2}} = 13.1$$

RELIABILITY IS $.9_{23}$

ALLOCATED RELIABILITY IS $.9_{6}8$ THEREFORE EROSION RELIABILITY IS ACCEPTABLE.

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE 3 OF
Sec D Continued.		DATE
		WORK ORDER
BY	CHK. BY	DATE

CALCULATE EROSION FOR INCREASE IN GAS TEMP FROM 4250°R TO 4500°R.

GAS SIDE WALL TEMP IS 1600°F

$$J = \frac{2025 - 1600}{\sqrt{25^2 + 34^2}} = 10.07.$$

RELIABILITY

.9 / 14 THEREFORE INCREASING GAS TEMP SHOULD NOT AFFECT TUBE EROSION.

SECTION D

4

```
U#=KFB17963,II
SYSTEM- FØR
NEW ØR ØLD--REL5**
WHAT?
ØLD
ENTER FILE NAME-REL5**
READY
RUN


REL5**       15:16PDT     05/15/72


TØLERANCE FACTØR...............?13.1

EQUIVALENT DEGREES ØF FREEDØM..?19

SAMPLE SIZE FØR MEAN...........?20

CØNFIDENCE LEVEL...............?0.90


              RESULTS------
    1 - RELIABILITY =                                0.76202157E-23
    INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =           9.99999535


READY
RUN

REL5**       15:17PDT     05/15/72


TØLERANCE FACTØR...............?10.07

EQUIVALENT DEGREES ØF FREEDØM..?19

SAMPLE SIZE FØR MEAN...........?20

CØNFIDENCE LEVEL...............?0.90


              RESULTS------
    1 - RELIABILITY =                                0.18376986E-14
    INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =           7.86552942

READY
```

AGCS-0800-11

REPORT NO.	PAGE 1 OF
SUBJECT: NOZZLE TUBE RUPTURE FMA VII E	DATE
	WORK ORDER
BY: R.G. Ackerman	CHK BY
DATE: 11/16/71	

DETERMINE WHAT IS REQUIRED TO MEET RELIABILITY ALLOCATION OF .9₀88 FOR CAT IV FAILURE ASSUMING 18 MECHANISMS 90% CONFIDENCE, AND SAMPLE SIZE = 20

THIS CORRESPONDS TO $J = 8.5$.

USE PARAMETERS AT NOZZLE AFT END.

NORMAL OPERATION END OF LIFE

SPEC 90770/23C	COOLANT PRESSURE $\bar{P}_c$	= 1375 PSI	D_p = 17.6
E	GAS PRESSURE $\bar{P}_g$	2 PSI	
1135000	MEAN TUBE RADIUS $\bar{R}$	0.386	D_R = .0032
"	MEAN TUBE THICKNESS $\bar{\tau}$	0.028	D_τ = 00033
E 25104 Run # 956005	TUBE WALL TEMP T_{MAX}	120.5°F	
DRM-112	MEAN STRENGTH $\bar{S}$	35,500 PSI.	
"	DESIGN BELOW S_{DES}	31,000 PSI.	
"	STRENGTH VAR. D_S	1960 PSI.	
	SAMPLE SIZE N	= 30	

SUBJECT TUBE RUPTURE SECTION E CONTINUED

DATE

WORK ORDER

BY RGA

CHK. BY

DATE 11/16/71

$$\bar{s} = \bar{P}\bar{R}/\bar{t}$$

$$= 1375 * 0.386 / .028$$

$$= 18,955$$

$$D_s^2 = \left(\frac{R}{t} D_P\right)^2 + \left(\frac{P}{t} D_R\right)^2 + \left(-\frac{PR}{t^2} D_t\right)^2$$

$$= \left(\frac{.386 * 17.6}{.028}\right)^2 + \left(\frac{1375 * .0033}{.028}\right)^2 + \left(\frac{1375 * .386 * .001}{.028^2}\right)^2$$

$$D_s = 367$$

$$s_{MAX} = 1428 * .396 / .027$$

$$= 20944$$

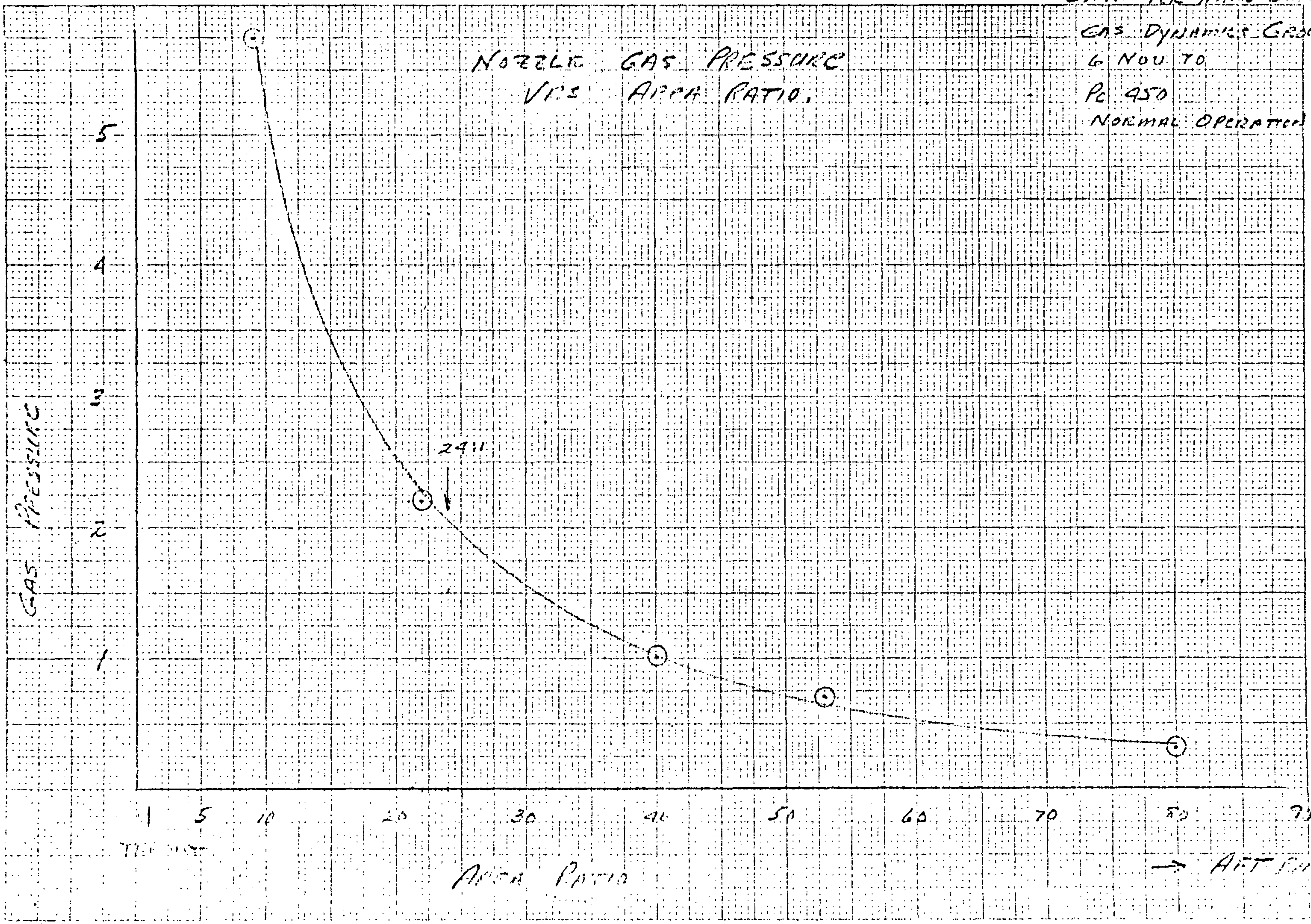
$$MS = \frac{.85 * 31000}{20944} - 1$$

$$= .258$$

NO. 340A-10½ DIETZGEN GRAPH PAPER
10 X 10 PER HALF INCH

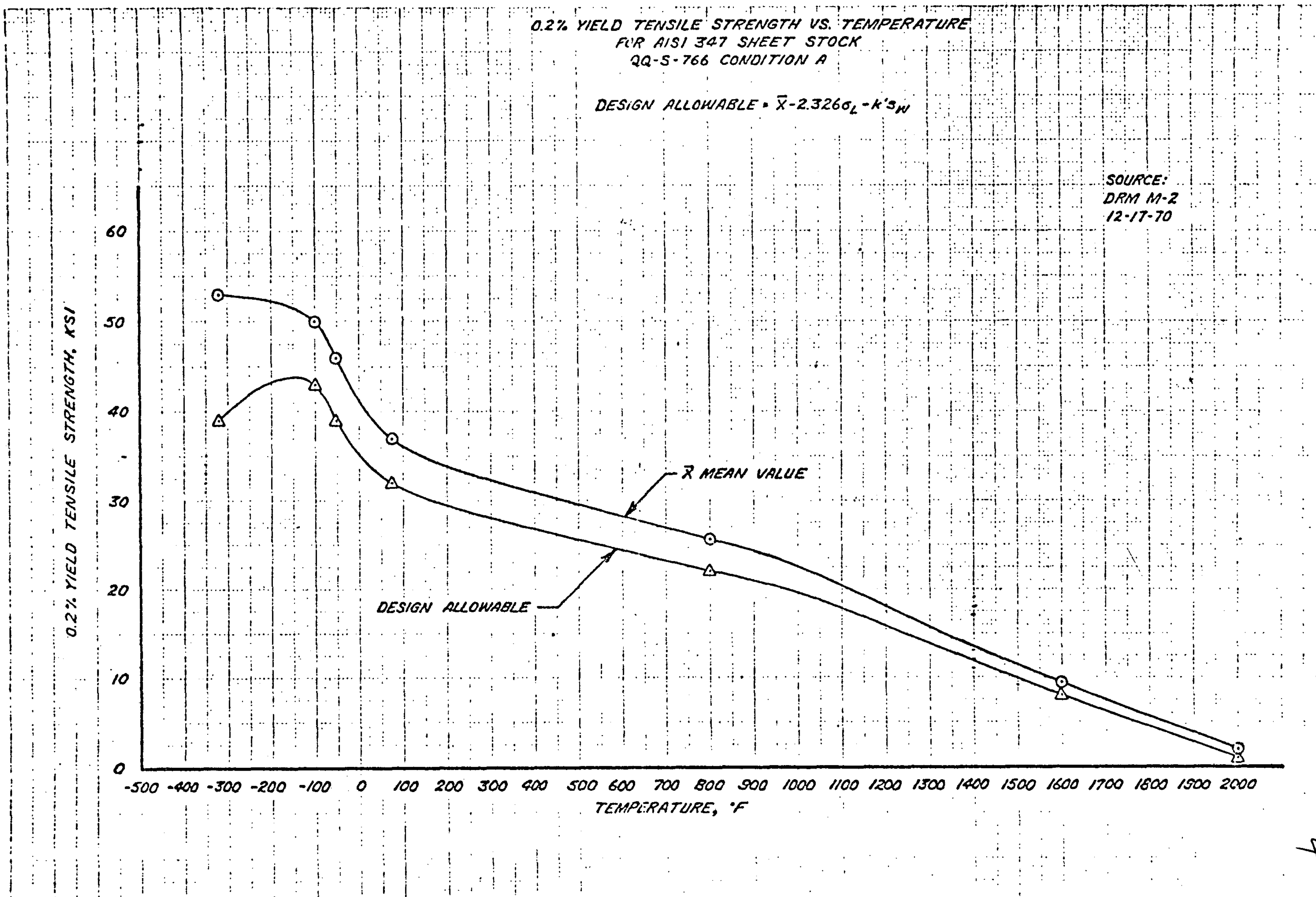
EUGENE DIETZGEN CO.
MADE IN U. S. A.

DATA PER MIKE DATORI
GAS DYNAMICS GROUP
6 NOV 70
Pc 450
NORMAL OPERATION.



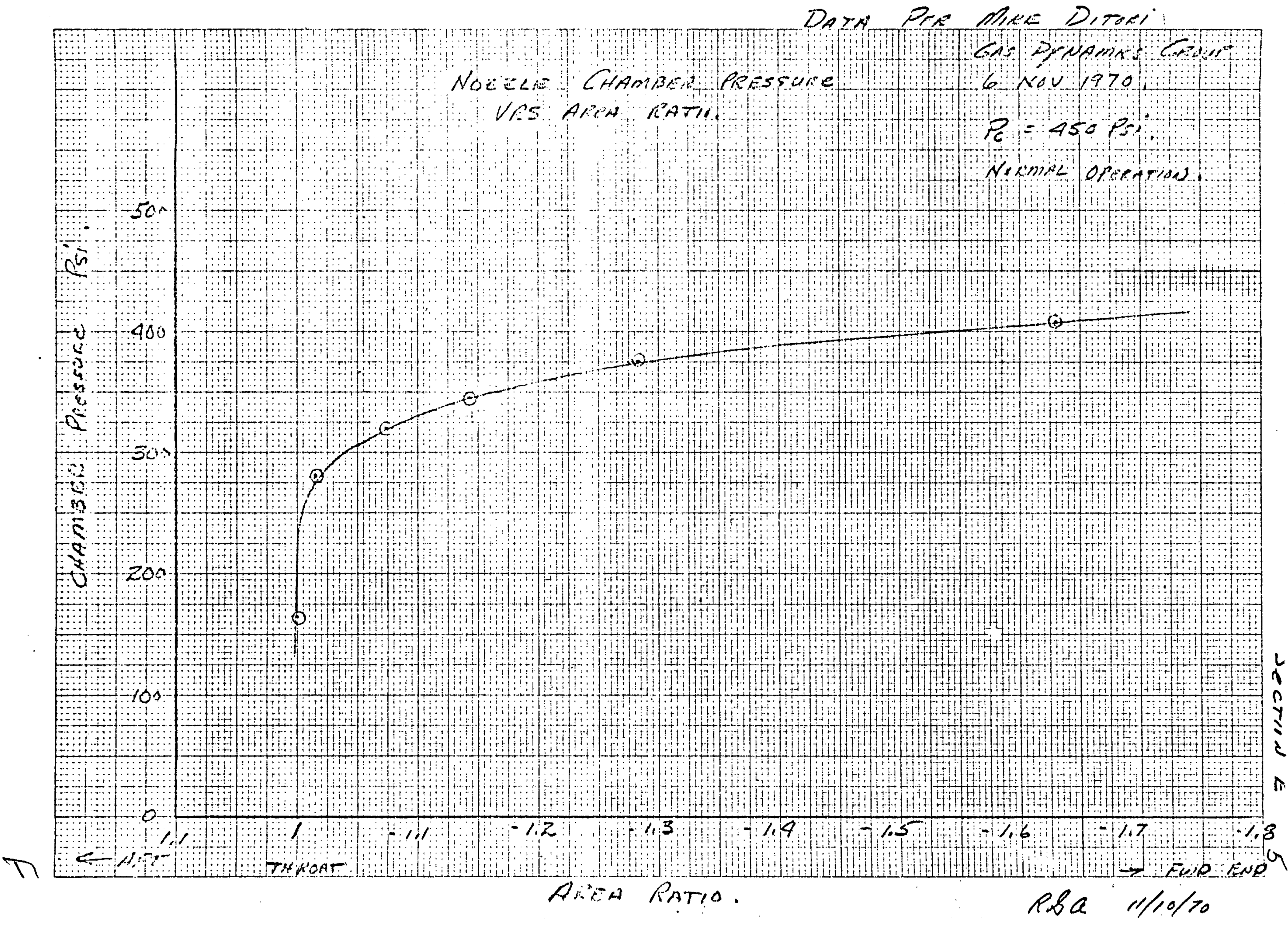
SECTION 3

RBR 11/10/70


0.2% YIELD TENSILE STRENGTH VS. TEMPERATURE
FOR AISI 347 SHEET STOCK
QQ-S-766 CONDITION A
DESIGN ALLOWABLE = $\bar{X}-2.326\sigma_L-k's_W$
SOURCE:
DRM M-2
12-17-70
$\bar{X}$ MEAN VALUE
DESIGN ALLOWABLE
0.2% YIELD TENSILE STRENGTH, KSI
0
10
20
30
40
50
60
-500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000
TEMPERATURE, °F

SECTION E

4


DATA PER MIKE DITORI
GAS DYNAMICS GROUP
6 NOV 1970.
NOZZLE CHAMBER PRESSURE
VRS AREA RATIO.
P_c = 450 PSI.
NORMAL OPERATIONS.
CHAMBER PRESSURE PSI.
500
400
300
200
100
0
1.1
1
-1.1
-1.2
-1.3
-1.4
-1.5
-1.6
-1.7
-1.8
← AFT
THROAT
→ FWD END
SECTION E
AREA RATIO.
RSA 11/10/70

AGCS-0800-11

REPORT NO.

PAGE 6 8 OF

SUBJECT: TUBE RUPTURE SECTION E CONTINUED

DATE

WORK ORDER

BY: RGA

CHK. BY

DATE 11/17/71

$$J = \frac{35500 - 18955}{\sqrt{1960^2 + 367^2}} = 8.30$$

RELIABILITY = .9$_{11}$58 ⟵ FOR N = 30
90% CONFIDENCE
REVISED D_S

ALLOCATION = .9$_{10}$ 8P

```
RUN

REL5**        10:44PST     11/17/71

TOLERANCE FACTOR...............?8.30

EQUIVALENT DEGREES OF FREEDOM..?29

SAMPLE SIZE FOR MEAN...........?30

CONFIDENCE LEVEL...............?0.90

           RESULTS------
   1 - RELIABILITY =                           0.41648932E-11
   INVERSE OF NORM. CUM. DIST. FUNCTION =      6.83275706

X
READY
RUN
```

AGCS-0800-11	REPORT NO.	PAGE 1 OF
SUBJECT: TUBE BUCKLING VII F		DATE
		WORK ORDER
BY: R.D. Ackerman	CHK. BY	DATE 10/18/71

SUMMARY & CONCLUSIONS.

THE EQUATIONS USED TO CALCULATE TUBE BUCKLING IN THIS ANALYSAS ARE BASED ON A TEST PROGRAM CONDUCTED AT NORTH AMERICAN ROCKWELL IN COLUMBUS OHIO.* THIS PROGRAM UTALIZED A TEST SPECIMEN CONSISTING OF CRES 347 U TUBES BRAZED INTO A 3/8 INCH THICK CRES 347 PLATE. THE TUBE CROWNS WERE INSTRUMENTED WITH STRAIN GAGES, AND A COMPRESSIVE STRAIN WAS APPLIED TO THE TUBE CROWNS BY BENDING THE PLATE.

THIS METHOD OF ANALYSIS IS CONSIDERED ACCURATE, AND SINCE RELIABILITY IS ADEQUATE, NO ADDITIONAL TESTS OR ANALYSIS IS RECOMMENDED.

* Ref RPT # NR71H-255 NORTH AMERICAN ROCKWELL, BY R.W. GEHRING.

AGCS-0800-11

SUBJECT	REPORT NO	PAGE 8 OF
TUBE BUCKLING VII F CONTINUED		DATE
		WORK ORDER
BY	CHK. BY	DATE

SUMMARY CONTINUED.

RELIABILITY IS: $.9_7 8$ FOR $4250°R$ T_q AT NORMAL OPERATION EOL.

RELIABILITY IS $.9_6 8$ FOR $4500°R$ T_q AT NORMAL OPERATION EOL.

ALLOCATION IS $.9_6 8$ FOR BUCKLING CATAGORY III FAILURE.

REVISED DATA.

AGCS-0800-11

	REPORT NO.	PAGE 1 OF
SUBJECT: TUBE BUCKLING - FMA VII F NORMAL THROTTLING E.O.L.		DATE
		WORK ORDER
BY: R.G. Ackerman	CHK. BY	DATE 10-18-71

— REVISED DATA —

TEMPERATURES USED BELOW ARE BASED ON COMPUTER PROGRAM E25104 RUN # 0956009 DTD 6-3-71. THIS REPLACES THE PREVIOUS ANALYSIS CONDUCTED 1-11-71 USING COMPUTER RUN # 71-005 AND MEMO N4320:M1608.

THE INPUT VARIABLES FOR THE OLD AND NEW PROGRAMS ARE AS FOLLOWS.

	-NEW- 0956009	-OLD- 71-005
P_c (PSIA)	265	285
T_c (°R)	4291	4318
ω_T (Lb/s)	53.5	57.2
ω_c (Lb/s)	39.0	38.7
P_{IN} (PSIA)	752	747
T_{IN} (°R)	56.2	49.9

AGCS-0800-11	REPORT NO.	PAGE 2 OF
SUBJECT: SECTION F CONTINUED		DATE
		WORK ORDER
BY: RZ GA	CHK. BY	DATE: 10-18-71

NORMAL THROTTLING END OF LIFE. $T_c = 4291$ $P_c = 265$

PROGRAM 0956009 — AT STATION 35

$T_{wg} = 1496°R$ $T_{wL} = 1148°R$

$\therefore T_{w_m} = 1322°R = 862°F$

JACKET WALL MEAN TEMP $= 80°F$ PER MEMO N4220:M1606

TUBE TO JACKET $\Delta T = T_{wm} - T_J =$

$= 862 - 80 = 782°F$

— ADD $300°$ UNCERTAINTY. — $782 + 300$

TUBE TO JACKET ΔT NOW $= 1082°F$

Design R/t Values —

$t = .022 \pm 001$

$R_g = 0.305 \pm 010$

NOMINAL $\overline{R/t} = .305/022 = 13.864$

MAX $R/t = 315/021 = 15.0$

$D_{R/t} = .3787$

375 8

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SUBJECT		REPORT NO.	PAGE 3 OF
TUBE BUCKLING VII F CONTINUED			DATE
			WORK ORDER
BY RGA.	CHK. BY		DATE 10-18-71

CRITICAL R/t FROM EQUATIONS DERIVED FROM TEST DATA Ref. NR71H-255 Pg 3

$$R/t_{NOM} = \sqrt[1.454]{\frac{1.258}{\alpha\ \Delta T}}$$

$$= \sqrt[1.454]{\frac{1.258}{10.6E{-}6 * 1082}}$$

$$= 25.30$$

$$R/t_{LOWER\ BOUND} = \sqrt[1.454]{\frac{.930}{\alpha\ \Delta T}}$$

$$= \sqrt[1.454]{\frac{.930}{10.6E{-}6 * 1082}}$$

$$= 20.55$$

$$D_{R/t} = (25.30 - 20.55)/3$$

$$= 1.58$$

SUBJECT

SECTIN VII F CONTINUED

DATE

WORK ORDER

BY R. G. [signature]

CHK. BY

DATE 10-18-71

RELIABILITY

$$J = \frac{25.30 - 13.864}{\sqrt{1.58^2 + .379^2}}$$

$$= 7.03$$

RELIABILITY = .9,8
               7

MARGIN OF SAFTY

$$M.S. = \frac{.85 * R/t_{\text{LOWER BOUND}}}{R/t_{\text{DESIGN MAX}}} - 1$$

$$= \frac{.85 * 20.55}{15.0} - 1$$

$$= +.16$$

AGCS-0800-11

SUBJECT	REPORT NO	PAGE 5 OF
THERMAL BUCKLING FMA VII F. CONTINUED		DATE
		WORK ORDER
BY R.B. Ackerman	CHK. BY	DATE 5/16/72

CONSIDER EFFECT OF INCREASE IN T_g FROM 4250 °R TO 4500 °R. THIS WILL INCREASE MEAN TUBE WALL TEMP (T_{wm}) BY 96° (REF NERVA EOR # N8120:71-015 dtd NOV 1971 BY L PICKERING.)

THIS WILL INCREASE THE NOZZLE TUBE TO JACKET ΔT FROM 1082 TO 1178 °F (SEE PG 2 OF THIS ANALYSIS FOR TEMP EVALUATION)

NOW THE CALCULATION OF R/t_{NOM} GOES AS FOLLOWS:

$$R/t_{NOM} = \sqrt[1.454]{\frac{1.258}{\alpha * \Delta T}}$$

$$= \sqrt[1.454]{\frac{1.258}{10.6E\text{-}6 * 1178}}$$

$$= 23.86$$

$$R/t_{\text{LOWER BOUND}} = \sqrt[1.454]{\frac{0.930}{\alpha \; \Delta T}}$$

$$= \sqrt[1.454]{\frac{0.930}{10.6\ E\text{-}6 * 1178}}$$

$$= 19.386$$

$$D_{R/t} = \left(R/t_{\text{NOM}} - R/t_{\text{LOWER BOUND}}\right)/3$$

$$= (23.86 - 19.386)/3$$

$$= 1.49$$

$$J = \frac{23.86 - 13.869}{\sqrt{1.49^2 + .379^2}}$$

$$= 6.5$$

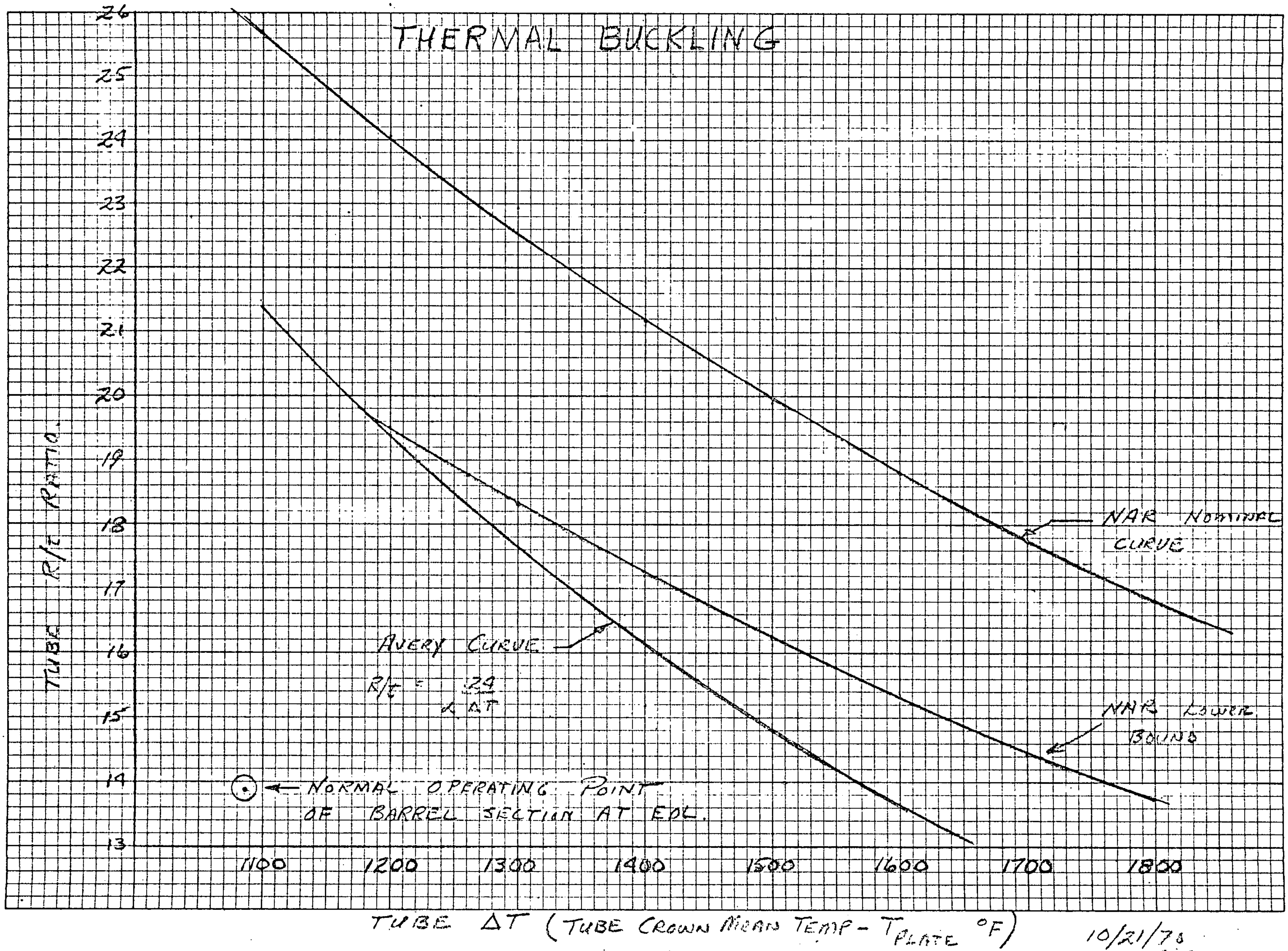
RELIABILITY = $9_6 8$ THEREFORE

BUCKLING WILL MEET ALLOCATION OF $9_6 8$ AT

INCREASED T_{AW} OF 4500 °R.

NO. 340A-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH

EUGENE DIETZGEN CO.
MADE IN U. S. A.



10/21/78

SECTION F

7

Section F

8

```
MARK II USERS PLEASE LIST INFØRM*** FØR IMPØRTANT INFØRMATIØN

U#=LFB17963,0 DELETED
LFB17963,II
SYSTEM--FØR
NEW ØR ØLD--ØLD
ENTER FILE NAME-REL5**
READY
RUN


REL5**        15:10PDT     10/18/71


TØLERANCE FACTØR...............?7.03

EQUIVALENT DEGREES ØF FREEDØM..?19

SAMPLE SIZE FØR MEAN...........?20

CØNFIDENCE LEVEL...............?0.90
```

VII F

```
             RESULTS------
    1 - RELIABILITY =                                  0.21695871E-07
    INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =             5.47646058
```

9,783
 7

```
PRØGRAM STØP AT 350

USED    2.35 UNITS


RUN


REL5**        15:12PDT     10/18/71


TØLERANCE FACTØR...............?7.92

EQUIVALENT DEGREES ØF FREEDØM..?19

SAMPLE SIZE FØR MEAN...........?20

CØNFIDENCE LEVEL...............?0.90
```

VII D

```
             RESULTS------
    1 - RELIABILITY =                                  0.32758134E-09
    INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =             6.17655289
```

9,67
 9

```
PRØGRAM STØP AT 350

USED    3.96 UNITS
```

FMA VII SECTION G NOZZLE TUBE LOW CYCLE THERMAL FATIGUE

SUMMARY AND CONCLUSIONS

A comprehensive thermal fatigue test program has been conducted on CRES 347 material at NERVA operating conditions. Results of the program show the low cycle fatigue reliability is $.9_{8}8$, exceeding the allocation of $.9_{7}0$. The test program and subsequent statistical analysis also shows no degradation in cyclic life due to the effects of 10 minute engine operations on each cycle. Results of the test program are shown in Figure 1, 2, and 3.

It is concluded that low cycle fatigue reliability is within the specified limits, and no additional testing is required to prove the acceptability of the tube design with respect to the fatigue failure mechanism.

TECHNICAL DISCUSSION

The NERVA nozzle utilizes CRES 347 U tubes brazed into an ARMCO 22-13-5 outside shell or jacket. The U tubes conduct low temperature hydrogen from the inlet at the lower end of the nozzle to the upper end where it is discharged into the pressure vessel plenum. The hydrogen bulk temperature averages approximately -360°F as it passes through the nozzle. As a result, the nozzle jacket operates at a low temperature while the tube crowns, which are exposed to 4250°R gas, operate near 1500°F, Reference a. This thermal gradient develops a strain on the tubes as they try to expand while being restricted by the jacket. The amount of strain varies according to the test conditions, however the most severe strain is 1.96% at the outside surface of the tubes crown under normal operating conditions. (Max flux point with T_g = 4250°R). The corresponding tube wall temperature at that point is 1484°F. The strain calculations are discussed in Reference b.

It was recognized early in the program that thermal fatigue was a problem that would require further evaluation. This was especially apparent when the number of engine operating cycles was increased to 60.

A preliminary reliability calculation was conducted to determine extent of the problem. The calculations were based on research work by S. S. Manson of Lewis Research Center (Reference c). The method used was based on actual test data but without the creep effect damage caused by hold time. To account for the effect of 10 minute engine operation on each cycle, the cyclic life was reduced by 80% as recommended in Reference c. This produced a reliability value of 0.76, while the allocated value is $.9_7$. The low reliability value was caused primarily by the reduction in cyclic life to account for hold time.

The problem of thermal fatigue appeared to be significant, and to provide actual data on CRES 347 material, and to evaluate the effect of hold time a test program was undertaken. The tests were conducted at Battelle Memorial Institute in Columbus, Ohio, and are described in Reference d and Reference e. A total of 172 tests were conducted at temperatures of 1000°F, 1400°F, and 1600°F with no hold time, and at strain values of between 1.5 and 5%. An additional 14 specimens were tested at 1400°F and 1600°F with a 10 minute hold time at the test temperature. The tests utilized CRES 347 bar stock that had been subjected to simulated NERVA braze cycles. The specimens were then tested in a hydrogen environment to simulate actual NERVA engine operating conditions.

The data from the tests was reduced by a regression analysis to provide mean values of cyclic life and standard deviations for a reliability analysis.

The statistical analysis results were used to conduct new reliability calculations for thermal fatigue. The calculations indicated that the reliability of the NERVA nozzle tubes for 60 cycles of operation is $.9_8 8$; this exceeds the allocation of $.9_7 0$. In addition, statistical analysis of the test data indicates there is no degradation in cyclic life due to the 10 minute hold time. Therefore it can be assumed that the overall thermal fatigue reliability is $.9_8 8$ and thermal fatigue thus becomes a very remote probability for 60 cycles of engine operation.

REFERENCE LIST

a. ANSC Memo N4320:M1672, J. J. Williams to J. L. Watkins, dtd 8 April 1971, Subj: Steady State Temperature Distribution in the NERVA Nozzle Coolant Channels

b. ANSC Engineering Operation Report 8120:R71-015, J. L. Pickering dtd 8 Nov 1971, Subj: NERVA 75K Nozzle U Tube Strain Analysis

c. Lewis Research Paper, Subj: A Method of Estimating High Temperature Low Cycle Fatigue Behavior of Materials by S. S. Manson and G. Halford

d. Battelle Laboratories Report, dtd 20 Dec 1971, Subj: Low Cycle Fatigue of Type 347 Stainless Steel and Hastelloy X in Hydrogen Gas Environment by C. E. Jaske and T. L. Porfilio.

e. ANSC Engineering Operation Report, 8120R:72-032, dtd 27 April 1972 Subj: Isothermal-Strain Controlled (Compression) - Low Cycle Fatigue Test of Type 347 Stainless Steel and Hastelloy X at Elevated Temperatures by L. Pickering

CRES 347 CYCLES TO FAILURE VS STRAIN .99/.95 LINES
(NO HOLD TIME EXCEPT AS INDICATED FOR 1400° F AND 1600° F)

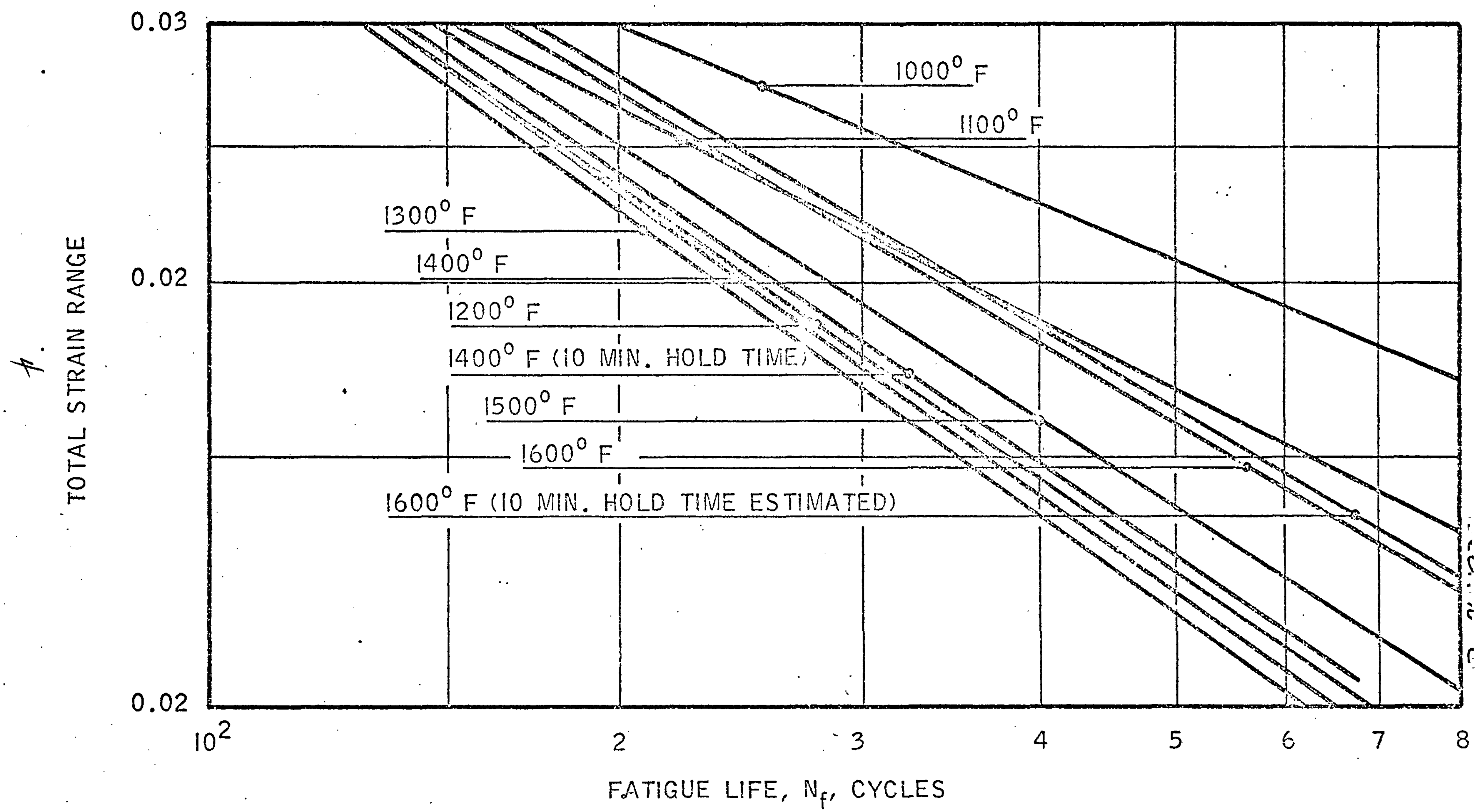
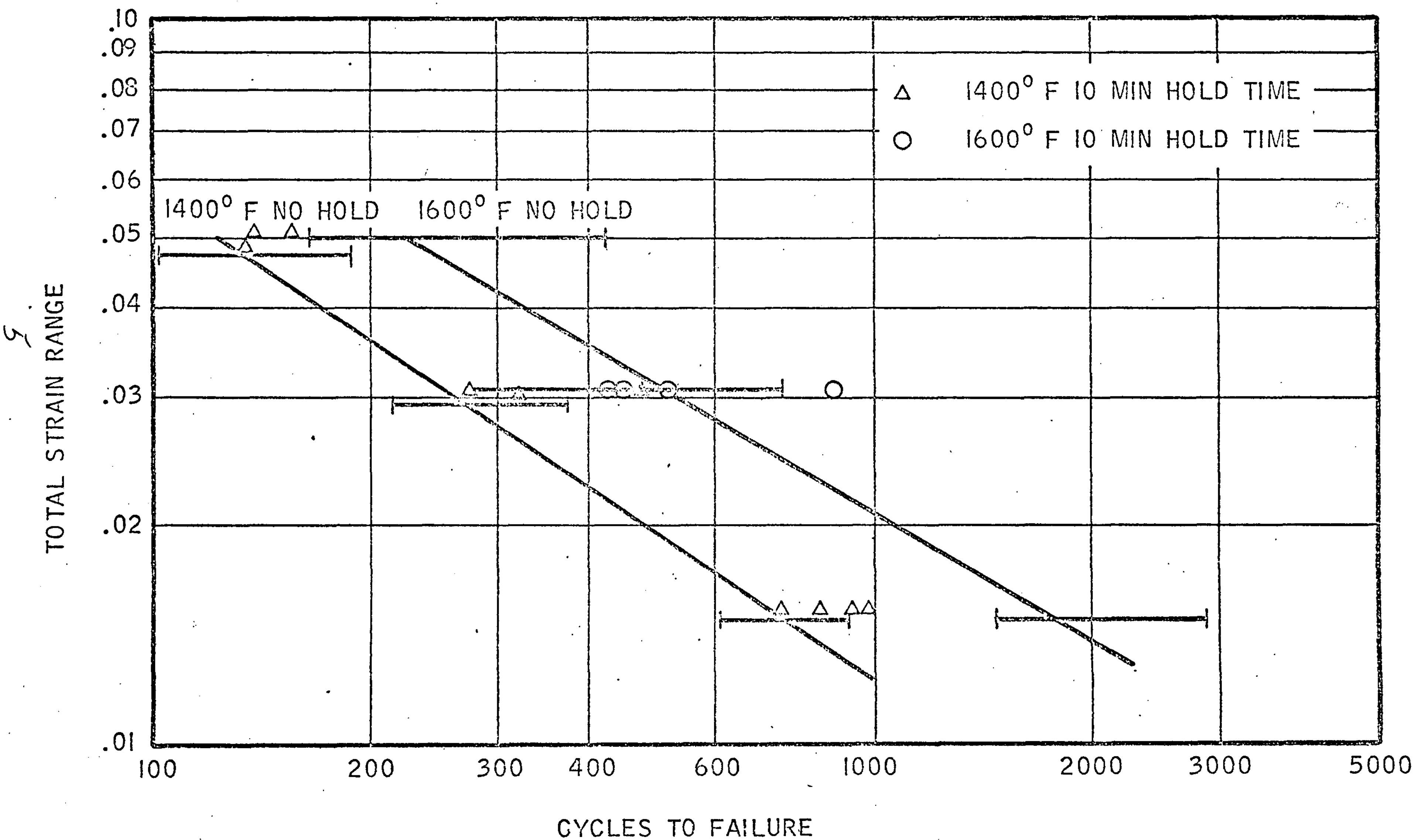


Fig 1

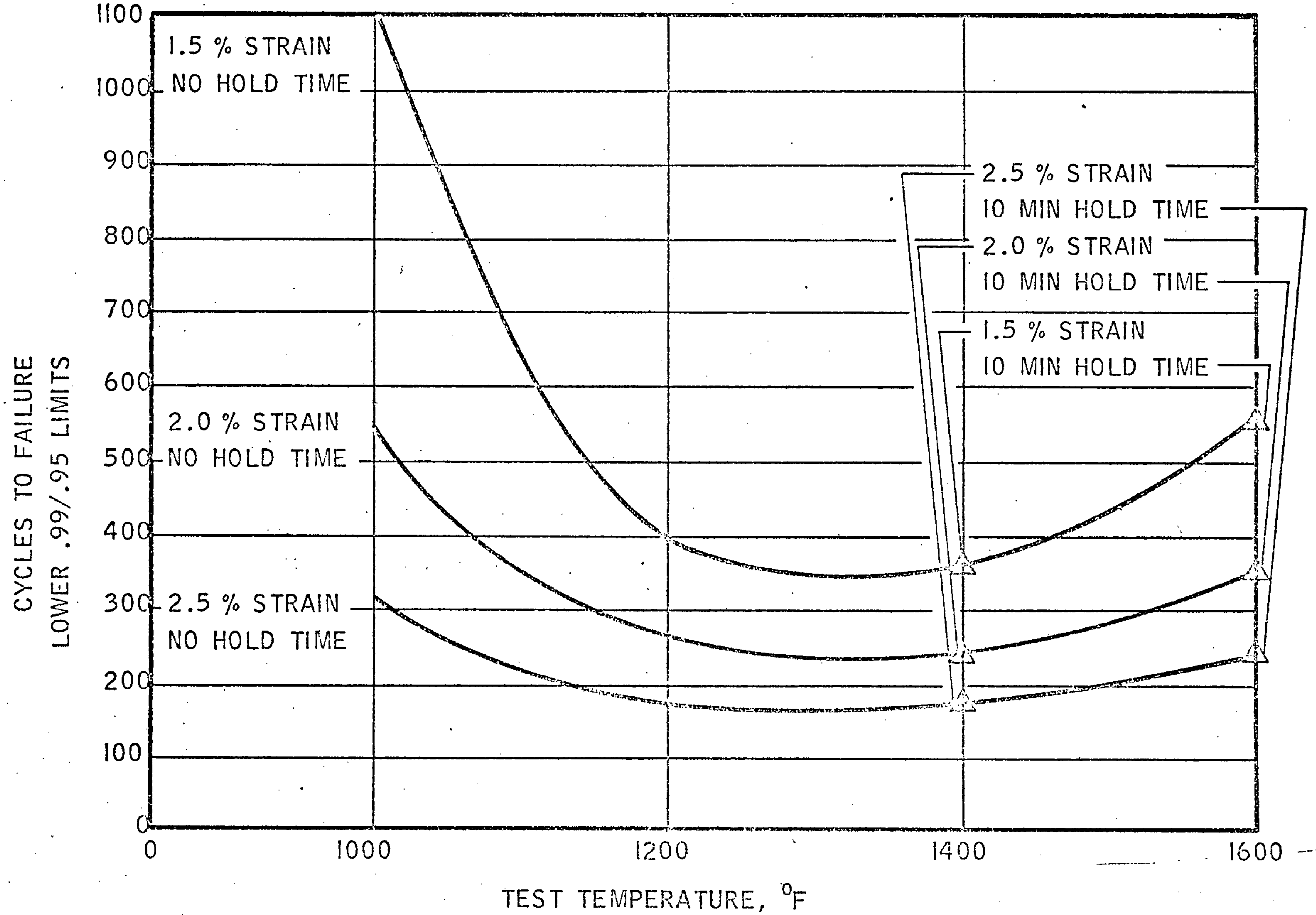
CRES 347 CYCLES TO FAILURE VS STRAIN
MEAN CURVES AND DATA SPREAD FOR NO HOLD TESTS
PLUS TEST DATA POINTS FOR 10 MIN HOLD TIME TESTS



SECTION G

Fig 2

CRES 347 CYCLES TO FAILURE VS TEMPERATURE



SECTION G

Fig 3

Definition of Terms.

ϵ_{P*} = EFFECTIVE PLASTIC STRAIN = ϵ_{PT} COMBINED WITH ϵ_{PA} BY EQUATION.

ϵ_{PA} = AXIAL PLASTIC STRAIN

ϵ_{PT} = TANGENTIAL PLASTIC STRAIN.

$D_{\epsilon_{P*}}$ = 1 STD DEVIATION OF PLASTIC STRAIN.

$C_N = D_{\epsilon_{P*}} / \bar{\epsilon}_{P*}$

μ_Δ = MEAN PLASTIC STRAIN TRANSFORMED FOR LOG NORMAL DISTRIBUTION

σ_Δ = 1 STANDARD DEVIATION IN PLASTIC STRAIN TRANSFORMED LOG NORMAL DISTRIBUTION.

$\sigma^2_{N_f|\Delta}$ = STD DEV IN CYCLIC LIFE DUE TO VARIATION IN TESTING.

D_{N_f} = STD DEV IN CYCLIC LIFE DUE TO COMBINED VARIATION OF OPERATION + TESTING. (CONTAINS σ^2)

DEFINITION OF TERMS - CONTINUED.

$\bar{N}_f$ = MEAN CYCLES TO FAILURE AS DETERMINED BY BATTELLE TESTS - $N_f = f(\mu_o)(T)$

N_0 = MINIMUM ALLOWABLE CYCLES TO FAILURE SPECIFIED BY ENGINE SPEC. ie 60 N

FOR 1000° DATA WHERE N_f VRS ϵ_p IS A QUADRATIC THE DISTRIBUTION IS ASSUMED TO BE LOG LOG NORMAL

TO USE THIS DISTRIBUTION, THE FOLLOWING ADDITIONAL TERMS ARE REQUIRED.

$$C_{x_1} = \frac{\ln D_{Nf}}{\ln N_f}$$

$$\ln \ln N_{f_1} = \ln \ln N_f - \left\{ \left[\ln (C_{x_1} + 1) \right] / 2 \right\}$$

$$\ln \ln D_{Nf_1} = \sqrt{\ln (C_{x_1}^2 + 1)}$$

DEFINITION OF TERMS - CONTINUED -

β_1 = CONSTANT FROM BEST FIT EQUATION

β_2 = CONSTANT FROM BEST FIT EQUATION

$N_f = \alpha + \beta_1 x_1 + \beta_2 x$

AGCS-0800-11

REPORT NO.

PAGE 1 OF

SUBJECT THERMAL FATIGUE RELIABILITY. FMA VII. G

DATE

WORK ORDER

BY R.D. Ackerman

CHK. BY

DATE 11/8/71

CALCULATE FATIGUE RELIABILITY USING STRESS FROM FINITE ELEMENT STRESS PROGRAM AND TEST DATA FROM BATTELLE.
Ref N8200; m3053 DTD 18 OCT 1971

CALCULATE REL USING STRAIN AT TUBE SURFACE AND MID WALL STRAIN.

4250°R GAS TEMP.

(1) SURFACE STRAIN TUBE SURFACE TEMP = 1400°F

$\epsilon_{p*} = 1.96\%$ REPORT N8120; 099 19 NOV 71

$D_{\epsilon p} = .4036\%$. (CALCULATED FROM CLOSED FORM EQUATION)

$$C_x = \frac{D_{\epsilon p}}{\epsilon_{p*}} = \frac{.4036}{1.96} = .2059$$

$$\ln \mu_A = \ln \epsilon_{p*} - \{[\ln(C_x + 1)]/2\}$$

$$= \ln 1.96 - \{[\ln(.2059 + 1)]/2\}$$

$$= .5798$$

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SUBJECT: TUBE FATIGUE SECTION G CONTINUED	DATE
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BY: RGA CHK. BY	DATE 11/8/77

$$\ln \sigma_s^2 = \ln (C_x^2 + 1)$$

$$= \ln (.2059^2 + 1)$$

$$= .0415$$

$$\ln \sigma^2_{Nf/s} = .04109 \qquad \ln \beta = 1.45675$$

$$\ln D_{Nf} = \sqrt{(\ln \beta)^2 * (\ln \sigma_s^2) + (\ln \sigma_{Nf/s})^2}$$

$$= \sqrt{(1.45675)^2 * .0415 + .04109}$$

$$= .3594$$

$$\ln N_f = 7.18620 - 1.45675 \ln \mu_s$$

$$= 7.18620 - 1.45675 * .5798$$

$$= 6.3415$$

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REPORT NO.

PAGE 3 OF

SUBJECT: TUBE FATIGUE SECTION G CONTINUED

DATE

WORK ORDER

BY: RGA

CHK. BY

DATE: 11/8/71

$\ln N_f|_{\Delta=1.96} = 6.3415$ $N_f|_{\Delta=1.96} = 567.6$ cycles

$$J = \frac{\ln N_f - \ln N_0}{\ln D_{N_f}} = \frac{6.3415 - 4.0943}{.3594} = 6.253$$

RELIABILITY $= .9_6 42$ ALLOCATION IS $.9_6 89$

OUTSIDE SKIN STRAIN
1.96 % STRAIN 1900 °F DAT.

REDUCE N_f BY 30% TO ACCOUNT FOR HOLD TIME

$.7 N_f = 397.3$ CYCLES.

$\ln .7 N_f = 5.9849$

$$J = \frac{5.9899 - 4.09437}{.3594}$$

$= 5.2$

RELIABILITY $= .9_4 3$

OUTSIDE SKIN
1.96 % STRAIN
1900 °F DATA
N_f REDUCED BY 30%.

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REPORT NO.	PAGE 4 OF
SUBJECT: TUBE FATIGUE SECTION G CONTINUED	DATE
	WORK ORDER
BY: RCA / CHK. BY	DATE 8/11/71

THE CALCULATED RELIABILITY IS BELOW THE ALLOCATION OF .968 DUE TO THE LARGE VARIANCE IN THE TEST DATA.

TO BETTER EVALUATE THE PROBLEM A PROPOGATION OF VARIANCE ANALYSIS WAS CONDUCTED USING THEORETICAL EQUATIONS FOR THERMAL FATIQUE.

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SUBJECT: TUBE FATIGUE SECTION G CONTINUED	DATE
	WORK ORDER
BY: RGA CHK. BY:	DATE 11/9/71

USE RESULTS OF PROPOGATION OF VARIANCE ANALYSIS TO GET D_{ϵ_p}

$$\epsilon_{p_{eff}} = \frac{2}{\sqrt{3}}\left(\epsilon_{p_t}^2 + \epsilon_{p_t}\epsilon_{p_A} + \epsilon_{p_A}^2\right)^{1/2}$$

$\bar{\epsilon}_{p_t} = .004649$ $\qquad \epsilon_{p_t} + 1\sigma = .004649 + .00074$

$= .005389$

$\bar{\epsilon}_{p_A} = .017807$ $\qquad \epsilon_{p_A} + 1\sigma = .017807 + .00209$

$= .019897$

$$\bar{\epsilon}_{p_{eff}} = \frac{2}{\sqrt{3}}\left(.004649^2 + .004649 * .017807 + .017807^2\right)$$

$= .02370$

$$\epsilon_{p_{eff}} + 1\sigma = \frac{2}{\sqrt{3}}\left(.005389^2 + .005389 * .019897 + .019897^2\right)^{1/2}$$

$= .026637$

$D_{\epsilon_p} = .00293$

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SUBJECT: TUBE FATIGUE SECTION G CONTINUED	DATE
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BY: RGA · CHK. BY	DATE 11/9/71

$$C_x = \frac{D_{\epsilon_p}}{\epsilon_{p*}} = \frac{.00293}{1.96} = .149$$

$$\ln \mu_s = \ln \epsilon_{p*} - \{[\ln (C_x + 1)]/2\}$$

$$= \ln 1.96 - \{[\ln (.149+1)]/2\}$$

$$= .6035$$

$$\ln \sigma_s^2 = \ln (C_x^2 + 1)$$

$$= .0219$$

$$\ln \sigma_{N_f}^2 = .09109 \qquad \ln \beta = 1.45675$$

$$\ln D_{Nf} = \sqrt{(\ln \beta)^2 * (\ln \sigma_s^2) + \ln \sigma_{Nf}^2}$$

$$= \sqrt{1.45675^2 * .02109 + 09109}$$

$$= .2930$$

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SUBJECT	REPORT NO.	PAGE 7 OF
TUBE FATIGUE SECTION 6 CONTINUED FMA XII G		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 11-9-71

$\ln N_f = 6.3915$ CALCULATED ON PG 2

$$J = \frac{6.3915 - 4.0934}{.2930} = 7.673$$

RELIABILITY = 9₈8

OUTSIDE SKIN
NO HOLD TIME
1.96 % STRAIN
1400 °F
PROP OF VARIANCE USED TO FIND VARIATION.

REDUCE CYCLIC LIFE BY 30 % TO ACCOUNT FOR POSSIBLE EFFECT OF HOLD TIME.

$\ln .7 N_f = 5.9849$

$$J = \frac{5.9849 - 4.0934}{.2930} = 6.45$$

RELIABILITY = 9₆5

OUTSIDE SKIN
30 % REDUCTION FOR HOLD TIME
1400 °F
1.96 % STRAIN
PROP OF VARIANCE USED.

AGCS-0800-11	REPORT NO.	PAGE 8 OF
SUBJECT: TUBE FATIGUE $T_g = 4500°R$ SECTION G CONTINUED		DATE
		WORK ORDER
BY	CHK. BY	DATE

CALCULATE RELIABILITY OF TUBE FATIGUE AT THE MAXIMUM STRAIN LOCATION WHILE THE NOZZLE IS OPERATING AT 4500°R GAS TEMP.

PER REPORT N8120: 71-015 DTD 8 NOV 1971 (COVER MEMO N8120;099 DTD 19 NOV 71)

MAXIMUM STRAIN IS 2.45 % AND SURFACE TEMP IS 1150°F AT A LOCATION 55° FROM THE TUBE CROWN AT THE MAX FLUX POINT.

SINCE NO EQUATION EXISTS FROM ACTUAL TEST DATA, ONE WILL BE DEVELOPED BY INCREASING THE CONSTANT IN THE 1400° EQUATION. THE SLOPE WILL BE ASSUMED TO BE THE SAME.

FROM FIGURE 3, IT CAN BE SEEN THAT THE 99/95 VALUE OF N_f FOR 2.5 % STRAIN IS APPROX 180 AT 1400°F AND 200 AT 1150°F. THIS IS AN 11 % INCREASE IN CYCLIC LIFE DUE TO THE REDUCED TEMP.

THE EQUATION FOR MEAN N_f BASED ON 1400° DATA IS $\ln N_f = 7.18620 - 1.45675 \ln \mu_\Delta$

WHERE N_f = CYCLES TO FAILURE

μ_Δ = TOTAL STRAIN TRANSFORMED FOR LOG NORMAL DISTRIBUTION.

AT 2.5 % STRAIN THIS EQUATION SHOWN N_f = 348 CYCLES, INCREASE THIS BY 11 % PRODUCES 386 CYCLES.

THE CONSTANT 7.18620 WILL NOW BE INCREASED TO PRODUCE AN 11 % INCREASE IN N_f

SUBJECT: SECTION 6 CONTINUED
$T_g = 4500\,^\circ R$

DATE

WORK ORDER

BY | CHK. BY | DATE

$$C = \ln N_f + 1.45675 \ln \mu_a$$

$$= \ln 386 + 1.45675 \ln 2.5$$

$$C = 7.29064$$

THE EQUATION FOR 1150°F IS NOW

$$\ln N_f = 7.29064 - 1.45675 \ln \mu_a$$

ASSUME THE VARIATION IS THE SAME AS CALCULATED FOR 1400°F USING PROPOGATION OF VARIANCE. (SEE PG 6).

THEREFORE $C_x = .2059$ (PG 1)

$\ln D_{N_f} = .2930$ (PG 6)

$$\ln \mu_a = \ln 2.45 - \{[\ln(.2059 + 1)]/2\}$$

$$= .8024$$

SUBJECT: SECTION G CONTINUED

$T_g = 4500\,°R$

BY | CHK. BY | DATE | WORK ORDER | DATE

$$\ln N_f = 7.29064 - 1.45675 * .8024$$

$$= 6.1217$$

$$J = \frac{6.1217 - \ln 60}{.2930}$$

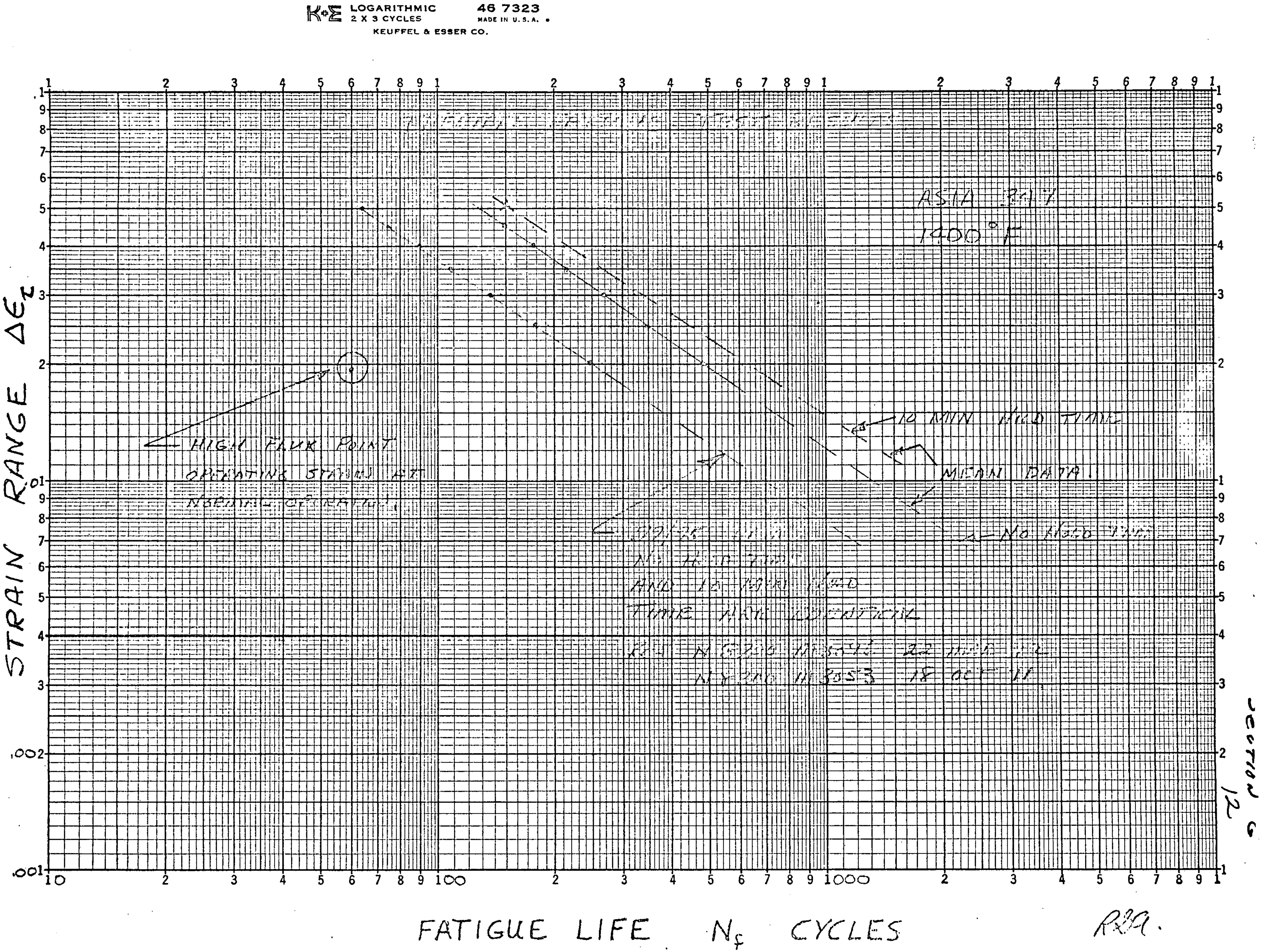
$$= 6.919$$

RELIABILITY IS .9₇64

ALLOCATION FOR THIS MODE IS .9₆89

THEREFORE RELIABILITY OF NOZZLE TUBES AT 4500 °R T_g OPERATION IS ADEQUATE.

```
REL5**       09:15PDT     05/30/72

TØLERANCE FACTØR...............?6.919

EQUIVALENT DEGREES ØF FREEDØM..?19

SAMPLE SIZE FØR MEAN...........?20

CØNFIDENCE LEVEL...............?0.90

          RESULTS------
  1 - RELIABILITY =                                 0.35406812E-07
  INVERSE ØF NØRM. CUM. DIST. FUNCTIØN =            5.38909435
```


K+E LOGARITHMIC 2 X 3 CYCLES
46 7323 MADE IN U.S.A.
KEUFFEL & ESSER CO.
ASTM 347
1400 °F
10 MIN HOLD TIME
MEAN DATA
NO HOLD TIME
HIGH FLUX POINT
OPERATING STRAIN AT
TIME ARE IDENTICAL
STRAIN RANGE $\Delta\epsilon_T$
.01
.002
.001
10
100
1000
FATIGUE LIFE N_f CYCLES
SECTION 12
RBA.

ARMCO 22-13-5 DESIGN.

DETERMINE STRESS IN THE BOLT COOLANT MANIFOLD DUE TO INTERNAL PRESSURE.

USE THE FOLLOWING PARAMETERS.

$\bar{P} = 1226$	$D_P = 13.3$	DRS 187 (14)
$R = .76$	$D_R = .0033$	1138000
$\tau = .140$	$D_\tau = .0006$	"

MATERIAL PROPERTIES.

PER ARMCO SCREENING PROGRAM –
Memo: 4350:MM 70-448 22 Dec 70

MEAN WALL TEMP = $-300°F$
PER 7731:M1487 DTD 15 JULY 70.

MEAN STRENGTH $\bar{S} = 110,000$ PSI

DESIGN ALLOW $S_{Des} = 86\,000$ PSI

$D_S = 8000$ PSI.

MEAN STRESS $\bar{s} = \bar{P}\bar{R}/\bar{t}$

$$= (1226 * .76)/.140$$

$$= 6655 \text{ PSI}$$

STRESS VARIANCE – BY PROPOGATION OF VARIANCE.

$$D_s^2 = \left(\frac{R * D_P}{t}\right)^2 + \left(\frac{P * D_R}{t}\right)^2 + \left(\frac{PR * D_t}{t^2}\right)^2$$

$$= \left(\frac{.76 * 13.3}{.140}\right)^2 + \left(\frac{1226 * .0033}{.140}\right)^2 + \left(\frac{1226 * .76 * .0006}{.140^2}\right)^2$$

$$D_s = 162.7$$

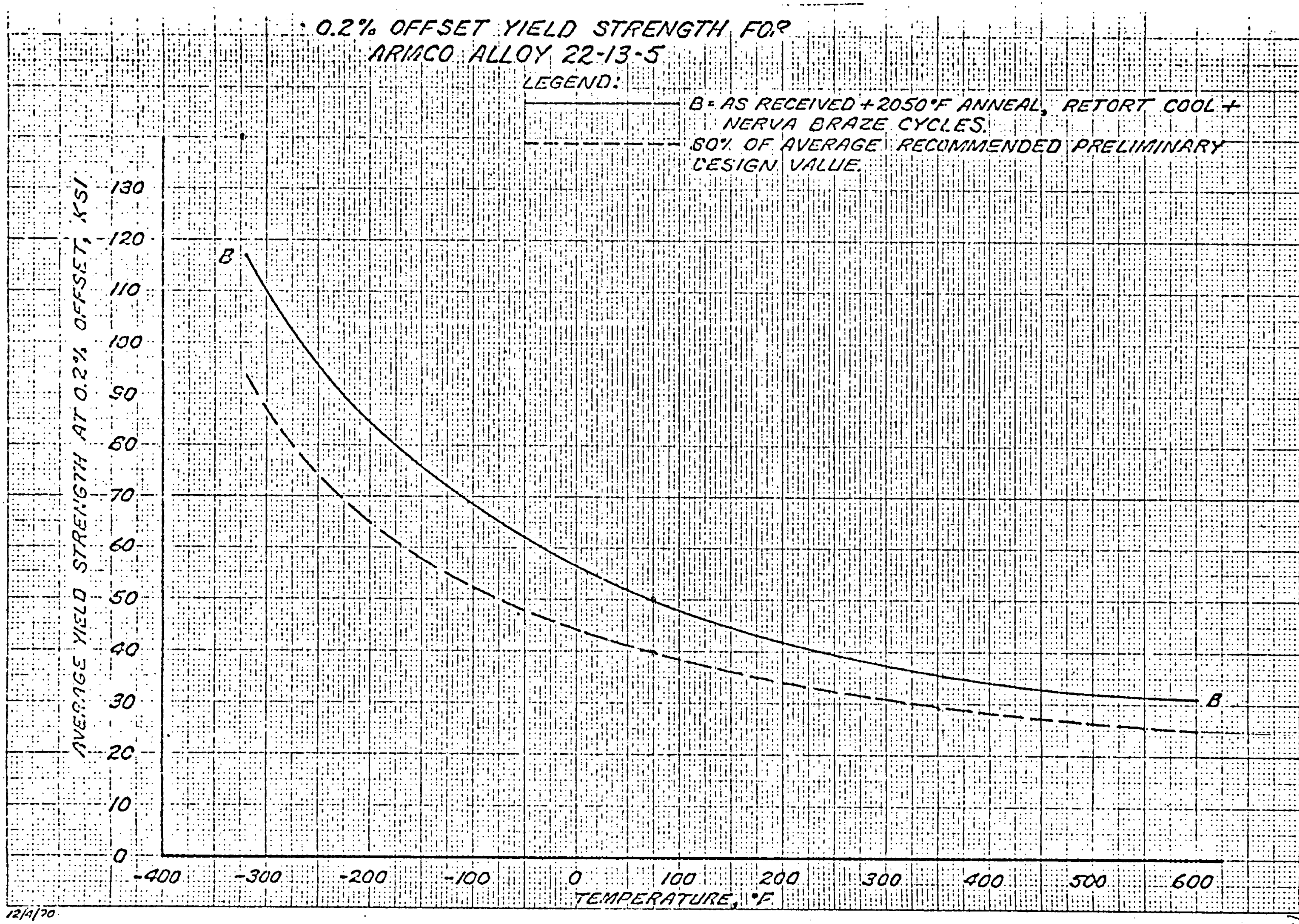
$$M.S. = \left[\frac{.85(86,000)}{6655 + 3 * 162.7}\right] - 1$$

$$MS = 9.2$$

$$J = \frac{110,000 - 6655}{\sqrt{8000^2 + 162^2}} = 12.9$$

RELIABILITY IS > $\cancel{.9_{19}}$ $.9_{23}$

Fig 2


0.2% OFFSET YIELD STRENGTH FOR
ARMCO ALLOY 22-13-5
LEGEND:
B = AS RECEIVED + 2050°F ANNEAL, RETORT COOL + NERVA BRAZE CYCLES.
80% OF AVERAGE RECOMMENDED PRELIMINARY DESIGN VALUE.
AVERAGE YIELD STRENGTH AT 0.2% OFFSET, KSI
130
120
110
100
90
80
70
60
50
40
30
20
10
0
B
B
-400
-300
-200
-100
0
100
200
300
400
500
600
TEMPERATURE, °F
12/4/70
SECTION A CONTINUED

15

Fig. 2

AGCS-0800-11

SUBJECT	REPORT NO.	PAGE 16 OF
BOLT COOLANT MANIFOLD ARMCO 22-13-5 FMA VII H.		DATE
		WORK ORDER
BY R. D. Ackerman	CHK. BY	DATE 6-4-71

THE RELIABILITY OF THE BOLT COOLANT MANIFOLD AS DESIGNED WITH A WALL THICKNESS OF .140 INCHES IS EXCESSIVE. IF NECESSARY A SMALL WEIGHT SAVING COULD BE ACCOMPLISHED BY REDUCING THE WALL THICKNESS HOWEVER THE SAVINGS PROBABLY WOULD NOT BE WORTH MAKING THE DRAWING CHANGE.

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SUBJECT	REPORT NO.	PAGE 17 OF
NOZZLE END CAPS. FMA VII I		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 3-22-71

SUMMARY AND CONCLUSION.

THE END CAP WAS ANALIZED USING A PLATE WITH FIXED EDGES. THIS WOULD BE THE CASE IF WE HAVE A COMPLETE BRAZE JOINT ARROUND THE END CAP. A MONTE CARLO RUN SHOWED ONLY .9,83 RELIABILITY, HOWEVER THE NUMBER OF RUNS WAS TO' LOW. (203) IF A SAMPLE SIZE OF 500 OR MORE HAD BEEN USED, RELIABILITY SHOULD BE GREATER THAN .9

THE CALCULATED RELIABILITY IS VERY HIGH HOWEVER NO SIGNIFICANT ADVANTAGE CAN BE GAINED BY REDUCING THE THICKNESS.

RECOMMEND DESIGN BE ACCEPTED AS IS.

AGCS-0800-11

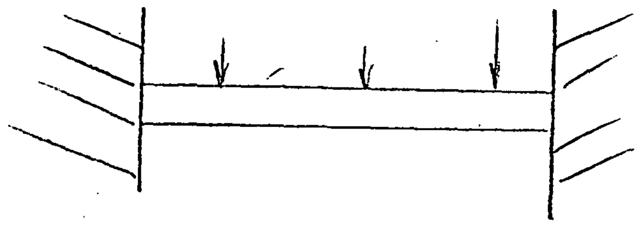
AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

REPORT NO.	PAGE 1 OF
	DATE
	WORK ORDER

SUBJECT

NOZZLE END CAPS, AFT END, FMA VII I

BY R.D. Ackerman | CHK. BY | DATE 3-22-71



ASSUME FIXED EDGES, - UNIFORM LOAD.

$A = \pi r^2/2 = \pi * .478^2 \text{ IN}/2 = .359$

$P = 1359 \pm 56 \qquad D_p = 56/3 = 18$ PSI.

$m = 1/\nu = 1/.29 = 3.45$

$t = 0.100 \pm .002 \qquad r = 0.478 \pm .010$

$D_t = 0006 \qquad D_r = .0033$

$$\bar{s} = \frac{3 P * A (m+1)}{8 \pi m t^2}$$

$$\bar{s} = \frac{3 * 1359 * .359 (3.45+1)}{8 \pi \; 3.45 \; .1^2}$$

$\bar{s} = 7511.7$ PSI.

TO FIND VARIANCE

ASSUME ν = POSSION'S RATIO = CONSTANT

$$\bar{s} = \frac{3 P \pi r^2 (m+1)}{8 \pi m \tau^2}$$

$$\bar{s} = \left(\frac{3 \cancel{\pi} (m+1)}{8 \cancel{\pi} m}\right)^{.484} \left(\frac{P r^2}{\tau^2}\right) \qquad \frac{3(m+1)}{8m} = .484$$

$$D_s^2 = \left(\frac{\partial s}{\partial P} D_P\right)^2 + \left(\frac{\partial s}{\partial r} D_r\right)^2 + \left(\frac{\partial s}{\partial \tau} D_\tau\right)^2$$

$$= \left(C \frac{r^2}{\tau^2} D_P\right)^2 + \left(\frac{C\, 2 P r}{\tau^2} D_r\right)^2 + \left(\frac{C\, 2 P r^2}{\tau^3} D_\tau\right)^2$$

$$= \left(\frac{.484 * .478^2 * 1P}{.1^2}\right)^2 + \left(\frac{.484 * 2 * 1359 * .478 * .0033}{.1^2}\right)^2$$

$$+ \left(\frac{.484 * 2 * 1359 * .478^2 * .0006}{.1^3}\right)^2$$

$$D_s = 339.4 \text{ PSI.}$$

MATERIAL STRENGTH. ASSUME PLATE STOCK.

$\bar{T} = 250^\circ R. = -210^\circ F$ Concept 8 NOBE 008 RLB.

$\bar{S} = 52,500$
$D_s = 4,000$ PSI.
Ref DRM M-2. 11/17/70

$$J = \frac{52,500 - 7511.7}{\sqrt{4000^2 + 339.4^2}}$$

$= 11.2$

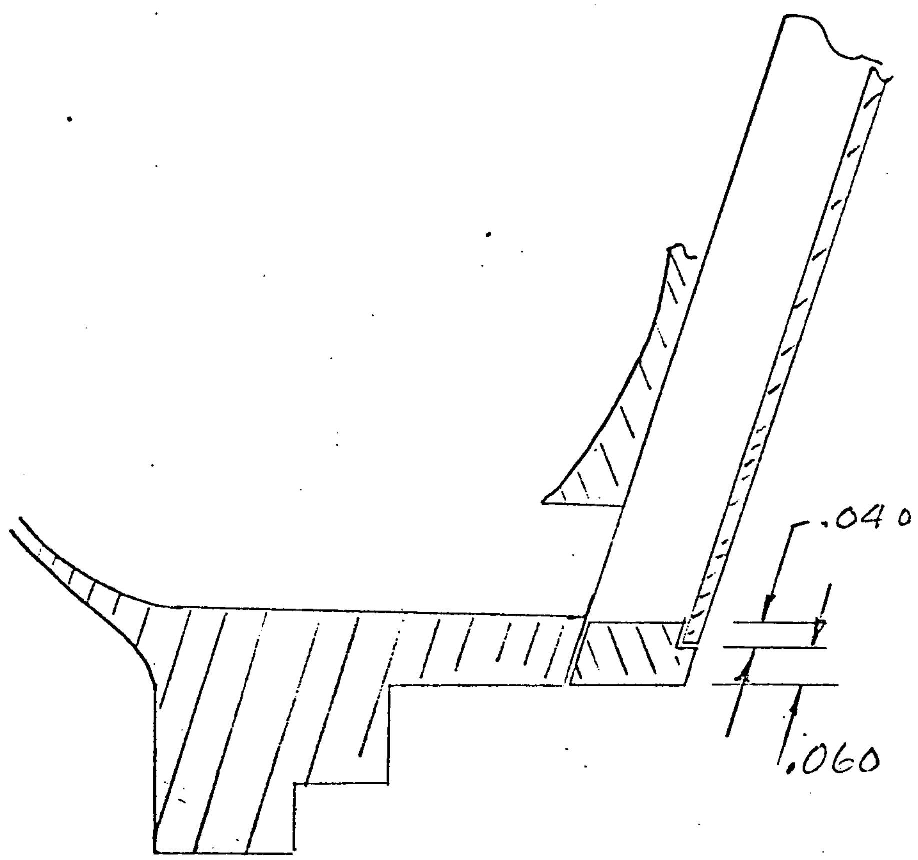
RELIABILITY ~~> .99~~ .9 18

RELIABILITY = .9 8 83 USING MONTE CARLO ANALYSIS.

$$M.S. = \frac{.85 * (52,500 - 3 * 4000)}{7511 + 3 * 339} - 1$$

$= +3.0$

Section I Continued



Section I

5

```
,USED      .02 UNITS
OLD ACKER
READY
LIST


ACKER         14:47 L      03/30/71

                     FMA PROGRAM INPUT


READY
OLD MONTE
FILE NOT SAVED
READY
OLD MONTE*
READY
RUN


MONTE*        14:48 L      03/30/71


        MONTE CARLO & SENSITIVITY ANALYSIS PROGRAM

IS THIS A MONTE CARLO OR SENSITIVITY ANALYSIS?
(ANSWER 'MONTE' OR 'SENS')?MONYE

DO YOU WANT TO USE STORED DATA FROM YOUR DATA-FILE?
(ANSWER 'YES' OR 'NO')?NO

NO. OF MONTE CARLO TRIALS & STARTING ODD INTEGER?50    28775

NO. OF INPUT VARIABLES?5


NO., NAME?, TYPE?, A?, B?, C?
  1?P      2         1359     18    0
  2?R      2         .478     .0033 0
  3?V      2         .29      .010  0
  4?T      2         ..100    .0006 0
  5?STRGTH  2        52500    4000  0


NO. OF CUMULATIVE PROBABILITY TABLES?  0


NO. OF OUTPUT VARIABLES & NO. OF VALUES TO BE RANKED?2   20


'*' - ANS 'YES' OR 'NO'
'?' - ANS WITH APPROPIATE VALUE OR NAME
NO., NAME?, REL*, HISTO*, NO. INTERVALS?, LWR*, VALUE?, UPR*, VALUE?
  1?  STRS  NO    YES          7          NO    0    NO    0
  2?  DIFF  YES   NO           7          NO    0    NO    0
```

DO YOU WISH TO STORE YOUR INPUT DATA? YES
FILE NAME, PLEASE? ACKER

SECTION I

6

---------- RESULTS FOR 50 MONTE CARLO TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
STRS	7510.	7549.	182.5	8007.	7082.
DIFF	0.4499E+05	0.4553E+05	4100.	0.5441E+05	0.3412E+05

DO YOU WANT MORE MONTE CARLO TRIALS? YES
HOW MANY ADDITIONAL TRIALS (RESULTS ARE CUMULATIVE)? 150

---------- RESULTS FOR 200 MONTE CARLO TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
STRS	7510.	7521.	181.8	8007.	7061.
DIFF	0.4499E+05	0.4511E+05	3818.	0.5441E+05	0.3412F+05

DO YOU WANT MORE MONTE CARLO TRIALS?NO

---------- RESULTS FOR VARIABLE STRS----------

	TABULAR HISTOGRAM				TEST FOR NORMAL	
VALUE	SIGMA	FREQ	CUM	CUM PROB	EXPECTED	DIFF.
7048.4836	-2.60	0	0	0.	0.004647	0.004647
7171.0911	-1.93	7	7	0.035000	0.027014	0.007986
7293.6985	-1.25	13	20	0.100000	0.105247	0.005247
7416.3059	-0.58	34	54	0.270000	0.281698	0.011698
7538.9134	0.10	51	105	0.525000	0.538477	0.013477
7661.5208	0.77	54	159	0.795000	0.779647	0.015353
7784.1282	1.45	30	189	0.945000	0.925828	0.019172
7906.7357	2.12	6	195	0.975000	0.982989	0.007989
HIGH END TAILS		5	200			

MAX DIFF. =0.019172

RELIABILITY ESTIMATED FROM SUCCESSES/POPULATION......R=1.0000000000
RELIABILITY ESTIMATED FROM LEAST SQUARES CURVE-FIT...R=0.9999999983 9/8/83
FROM THE 20 VALUES NEAREST ZERO, BELOW

0.341218E+05	0.343680E+05	0.350948E+05	0.360523E+05	0.372952E+05
0.377692E+05	0.377752E+05	0.378035E+05	0.380302E+05	0.382556E+05
0.383368E+05	0.385770E+05	0.388562E+05	0.389352E+05	0.390439F+05
0.392026E+05	0.398184E+05	0.398863E+05	0.398977E+05	0.399831E+05

CRITICAL DIFFERENCES (N GREATER THAN 50)

LEVEL OF SIGNIFICANCE				
20%	15%	10%	5%	1%
0.0757	0.0806	0.0863	0.0962	0.1153

PROGRAM STOP AT 496

```
USED    4.77 UNITS
```

Section I

1

```
OLD FA DELETED
OLD FMA
READY
LIST


FMA          15:00 L     03/30/71

100 FUNCTION F(X,Y)
110 REAL X(100),Y(25)
120 P=X(1);R=X(2);V=X(3);T=X(4);STRGTH =X(5)
130 Y(1)=3*P*(3.14159*R^2)/2*(1/V+1)/(8*3.14159*(1/V)*T^2)
140 Y(2)=STRGTH-Y(1)
150 RETURN;END


READY
UNSAVE
READY
OLD ACKER
READY
LIST


ACKER        15:01 L     03/30/71

          50        28775          5              0            2          20
           1            2   1.3590000E+03  1.8000000E+01   0.
           2            2   4.7800000E-01  3.3000000E-03   0.
           3            2   2.9000000E-01  1.0000000E-02   0.
           4            2   1.0000000E-01  6.0000000E-04   0.
           5            2   5.2500000E+04  4.0000000E+03   0.
      1  STRS  NO    YES      7  NO     0.               NO    0.
      2  DIFF  YES   NO       7  NO     0.               NO    0.


READY
UNSAVE
READY


BYE
0005.32  CRU    0000.39  TCH    0005.85  KC

OFF AT 15:03 L  03/30/71
```

AGCS-0800-11

REPORT NO.	PAGE 8 OF

SUBJECT: END CAP TO TUBE FAILURE.
FMA VII J.

DATE

WORK ORDER

BY | CHK. BY | DATE

SUMMARY AND CONCLUSIONS.

RELIABILITY CALCULATIONS SHOW THAT THE END CAP MUST BE INSERTED INTO THE TUBE ONLY .031 INCHES TO PROVIDE ACCEPTABLE RELIABILITY. MAXIMUM DEPTH OF INSERTION IS .100 INCHES.

THIS MEANS THAT Q.C. MUST INSURE THAT EACH END CAP IS INSERTED A MINIMUM OF .031, AND IT IS RECOMMENDED THAT A MINIMUM OF .050 INCHES BE USED TO ALLOW FOR SOME BRAZE VOIDS.

AGCS-0800-11

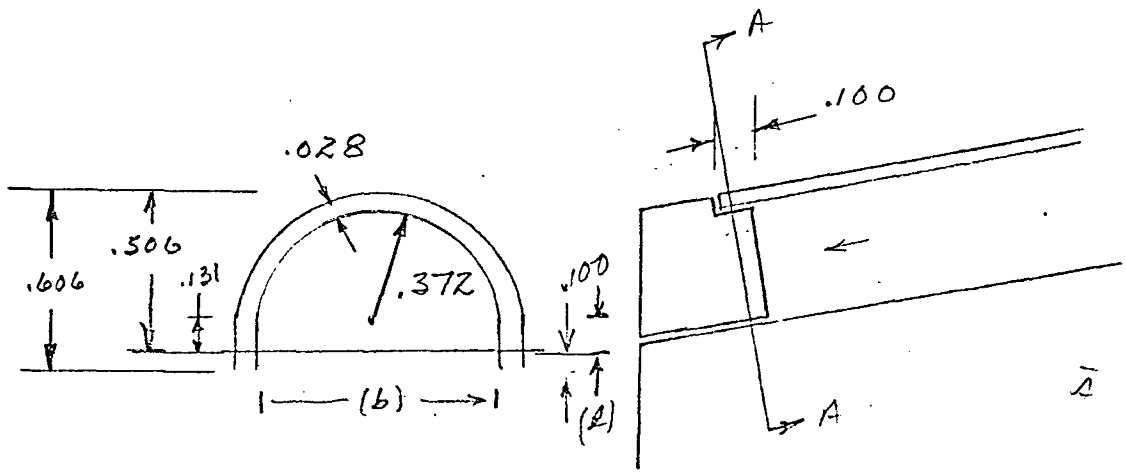
AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

SUBJECT: FMA VII J END CAP TO TUBE JOINT FAILURE	REPORT NO.	PAGE 1 OF
		DATE
		WORK ORDER
BY: R.G. Ackerman	CHK. BY	DATE 5-18-71

REVISED 10/29/71

DETERMINE RELIABILITY OF NOZZLE TUBE TO END CAP BRAZE JOINT DUE TO INTERNAL PRESSURE

EVALUATE FULL ENGAGEMENT, THEN DETERMINE MINIMUM ALLOWABLE BRAZE COVERAGE.



$F = P\left(\frac{\ell b}{10^3}\right) \times A$

$= lb.$

Y

$= \frac{F}{A}$

MATERIAL SHEAR STRENGTH — BASED ON BRAZE JOINT TESTS CONDUCTED DURING PHOEBUS PROGRAM. REF PHOEBUS MATERIALS FINAL REPORT RP-SR-0002. SEPT 1967

$\bar{S}_s = 61{,}300$ PSI.

$D_s = 3600$ PSI.

SUBJECT
END CAP SECTION J CONTINUED

DATE

WORK ORDER

BY

CHK. BY

DATE 5/18/71

REVISED 10/27/7

CAUTION:

MATERIALS DATA USE HERE WAS GENERATED FOR THE PHOEBUS PROGRAM 4 YEARS AGO, USING NIORO ALLOY WITH HAST X MATERIAL AT ROOM TEMP. THIS IS THE ONLY DATA AVAILABLE

IT IS RECOMMENDED THAT A TEST PROGRAM BE CONDUCTED DURING CY 73 TO TEST ARMCO JACKET SAMPLES WITH 347 TUBING, AND THE LATEST BRAZE ALLOY.

STRESS: ASSUME A .095 INCH WIDE BRAZE JOINT ARROUND END CAP.

CIRCUMFERENTIAL DISTANCE SEE FIG PG 1

$C = 2 * .372 + 2 * .131 + \pi * .372$

$C = 2.174$

BAZED AREA $= C * .095 = .2066$

AREA OF END CAP PRESSURE IS ACTING AGAINST

$A = \frac{\pi R^2}{2} + L * B$

$= \frac{\pi * .372^2}{2} + .131 * .744$

$= .315 \text{ IN}^2$

FORCE $F = P * A = 1359 * .315$

$= 428$ LB.

STRESS $= F/A = F/D(B + 2L + \pi R)$

$= 428 / .206$

$= 2072$ PSI.

WHERE D = DEPTH OF INSERTION

B = LENGTH OF BASE

R = INSIDE RADIUS

L = KEY HEIGHT.

F = 1359 * .315 = 428 LB. D_F = 18.6

D = .095 ± .005 D_D = .0016

B = .744 ± 005 D_B = .0016

R = .372 ± 003 D_R = .001

L = .131 ± 009 D_L = .003.

$$D_s^2 = \left(\frac{\partial s}{\partial F} D_F\right)^2 + \left(\frac{\partial s}{\partial D} D_D\right)^2 + \left(\frac{\partial s}{\partial L} D_L\right)^2 + \left(\frac{\partial s}{\partial R} D_R\right)^2$$

$$= \left(\frac{D_F}{D \times B + 2 \times L \times D + \pi \times R \times D}\right)^2 + \left(\frac{F * D_D}{D^2 (B + 2L + \pi R)}\right)^2$$

$$+ \left(\frac{F * D_L}{2L^2 D}\right)^2 + \left(\frac{F D_R}{\pi R^2 D}\right)^2$$

AGCS-0800-11

REPORT NO.	PAGE 5 OF
SUBJECT: END CAP BRAZE SECTION J CONTINUED	DATE
	WORK ORDER
BY: RGA	CHK. BY: REVISED	DATE: 10/29/71

$$D_s^2 = \left(\frac{18.6}{2.179 * .095}\right)^2 + \left(\frac{428 * .0016}{.95^2\left(.744 + \frac{.262}{2.179} + \pi * .372\right)}\right)^2$$

$$+ \left(\frac{428 * .003}{2 * .131^2 * .095}\right)^2 + \left(\frac{428 * .001}{\pi * .372^2 * .095}\right)^2$$

$$= 405$$

$$MS = \frac{.85(61300 - 3 * 3600)}{2072 + 3 * 405} - 1$$

$$= 14.9$$

$$J = \frac{61300 - 2072}{\sqrt{3600^2 + 405^2}}$$

$$= 16.3$$

RELIABILITY $> .9_{15}$

DETERMINE MINIMUM ENGAGEMENT REQUIRED FOR $.9_{10}88$ RELIABILITY. (J = 8.5)

$$J = \frac{\bar{S} - \bar{s}}{\sqrt{D_S^2 + D_s^2}}$$

$$\bar{s} = \bar{S} - J\sqrt{D_S^2 + D_s^2}$$

$$= 61300 - 8.5\sqrt{3600^2 + 405^2}$$

$$= 30{,}506$$

$$\bar{s} = F/A = F/D(B + 2L + \pi R)$$

$$= 2072/D * C$$

$$D = 2072/\bar{s} * C$$

$$= 2072/30{,}506 * 2.174$$

$$= .031 \text{ INCHES.}$$

AGCS-0800-11

SUBJECT	REPORT NO	PAGE 7 OF
END CAP TO JACKET WELD JOINT FMA VII K.		DATE
		WORK ORDER
BY R.D. Ackerman	CHK. BY	DATE 6-25-71

Summary And Conclusions.

These calculations indicate that reliability of this weld will exceed the allocation, and is therefore acceptable. Additional materials data should be developed to get a better estimate of the strength of the weld however. No data is available on CRES 347 to ARMCO 22-13-5, therefore the strength of ARMCO forging material was used as an estimate.

This calculation should therefore be considered as a preliminary estimate.

SUBJECT FMA VII K END CAP TO JACKET JOINT.

DATE

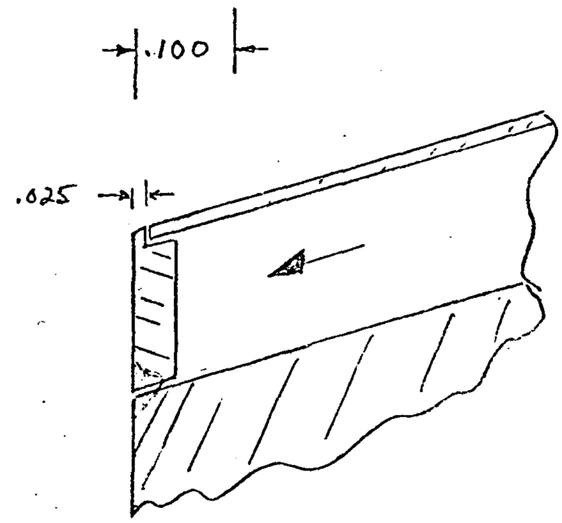
WORK ORDER

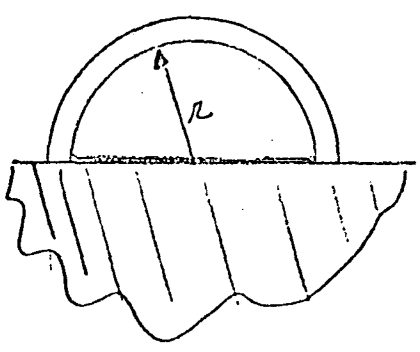
BY R.B. Ackerman

CHK. BY

DATE 6-25-71

CALCULATE WELD STRENGTH ASSUMING HELP FROM BRAZE JOINT. EVALUATE MINIMUM WELD REQUIRED TO PROVIDE ACCEPTABLE RELIABILITY AND A POS M.S.





MATERIAL PROPERTIES.

THE END CAP WELD COULD FAIL IN EITHER SHEAR OR TENSILE, HOWEVER, THE TENSILE STRENGTH IS LOWER SO IT WILL BE USED AS THE FAILURE CRITERIA. DATA PER N4350:MM 70-442

MATERIAL TEMP PER RPT N8110; M1710

Material Temp at Weld Joint $\bar{T} = -45°F$

$\bar{S}_Y = 62000$ PSI

$S_{Y\,DES} = 47{,}000$ PSI

$D_S = 3900$ PSI.

FORCE ACTING ON END CAP.

AREA OF SURFACE PRESSURE IS WORKING AGAINST

$A = \frac{\pi r^2}{2} + L \times b$ $\quad$ b = base $\quad$ L = Leg Height

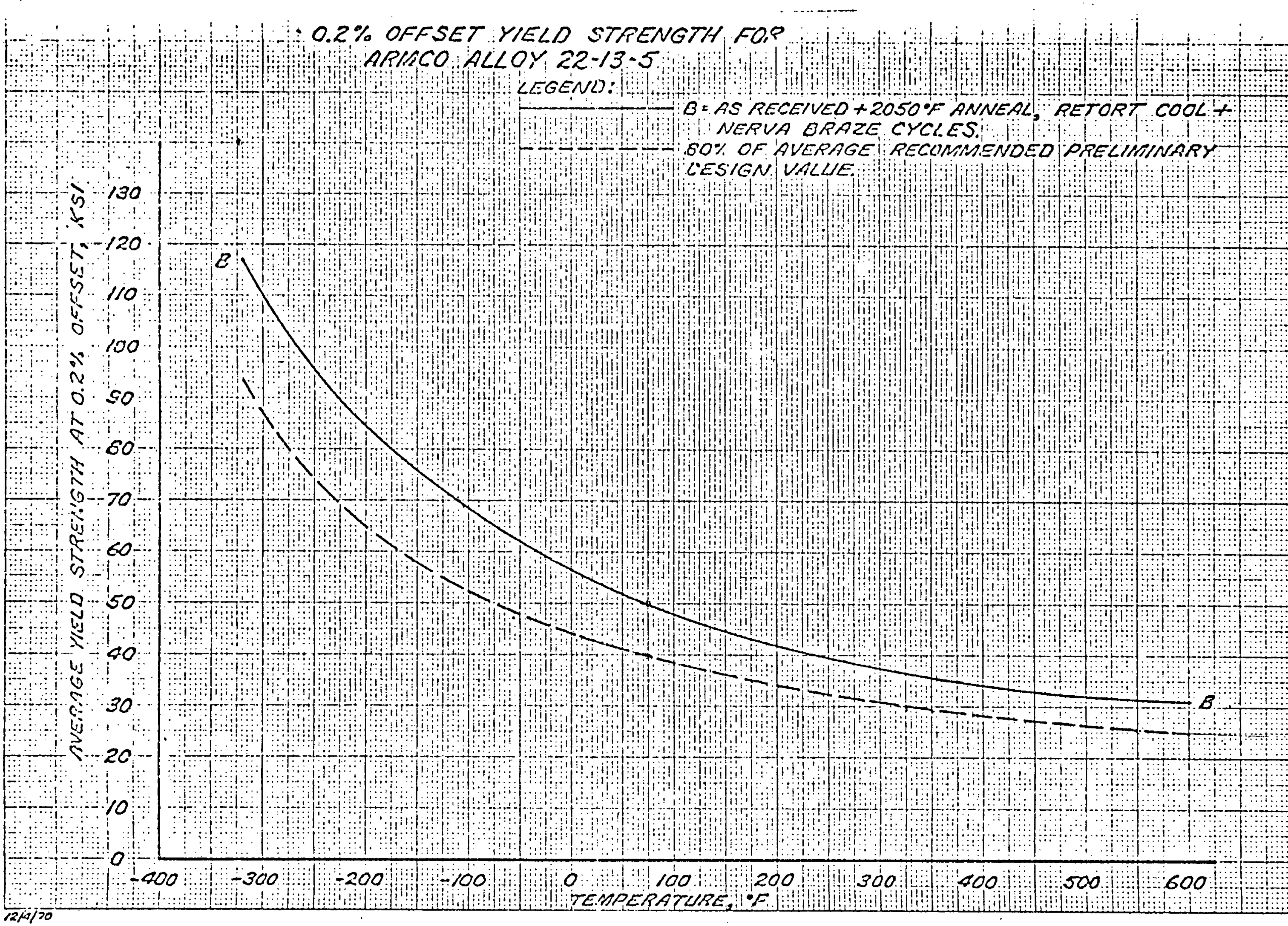
$= \frac{\pi \times .372^2}{2} + .106 \times .744$

$A = .296 \text{ IN}^2$

$F = P/A = 1384/.296$

$= 4675$ LB

Fig 2



SECTION K

28

GEOMETRY OF END CAP.

LENGTH OF WELD $\bar{b} = .744$ IN $D_b = .0006$

RADIUS OF END CAP $\bar{r} = .372$ IN $D_r = .0003$

LEG HEIGHT $\bar{l} = .106$ IN $D_l = 0006$

THICKNESS OF WELD $\bar{t} = .100$ IN $D_t = .001$

PRESSURE $\bar{P} = 1384$ PSI. $D_p = 18$

CIRCUMFERENTIAL DISTANCE ARROUND END CAP.

$$C = 2\pi r + 2l + b$$

$$= \cancel{2}\pi * .372 + 2 * .106 + .744$$

$$= 1.168 + .216 + .744$$

$$= 2.128$$

LENGTH OF WELD (.744) IS 35% OF TOTAL CIRCUMFERENCE.

∴ 35% OF FORCE ACTS ON THE WELD.

SECTION K CONTINUED

$$F = 4675 * .35$$
$$= 1673 \text{ Lb}$$

AREA OF WELD = .744 * .1

$$\bar{s} = F/A = 1673/.074$$
$$= 22,110$$

THE ABOVE EQUATIONS REDUCE TO THE FOLLOWING EQUATION FOR STRESS

$$\bar{s} = \frac{.35\ P}{\frac{\pi r^2}{2} b T + b^2 L T}$$

SUBJECT

SECTION K CONTINUED

USING PROPOGATION OF VARIANCE TO DETERMINE STRESS VARIANCE,

$$D_s = \left(\frac{\partial s}{\partial P} D_P\right)^2 + \left(\frac{\partial s}{\partial r} D_r\right)^2 + \left(\frac{\partial s}{\partial b} D_b\right)^2 + \left(\frac{\partial s}{\partial \tau} D_\tau\right)^2 + \left(\frac{\partial s}{\partial L} D_L\right)^2$$

$$D_s = \left(\frac{2 D_P}{\frac{\pi r^2}{2} b \tau + b^2 L \tau}\right)^2 + \left(\frac{-2 \;\; 2P \;\; D_r}{\pi r^3 b \tau}\right)^2$$

$$+ \left(\frac{2P \quad D_b}{\pi r^2 b^2 \tau - 2 \times 2 b^3 L \tau}\right)^2$$

$$+ \left(\frac{2 P D_\tau}{\pi r^2 b \tau^2 - 2 b^2 L \tau^2}\right)^2$$

$$+ \left(\frac{\cancel{2} P D_L}{\cancel{2} b^2 L^2 \tau}\right)^2$$

$$D_s = \left(\frac{2*18}{\frac{\pi*.372^2}{2}*.744*.1 + .744^2*.106*.1}\right)^2$$

$$+ \left(\frac{2*1384*.0003}{\pi*.372^3*.744*.1}\right)^2$$

$$+ \left(\frac{2*1384*.0006}{\pi*.372^2*.744^2*.1 - 2*2*.744^3*.106*.1}\right)^2$$

$$+ \left(\frac{2*1384*.01}{\pi*.372^2*.744*.1^2 - 2*.744^2*.106*.1}\right)^2$$

$$+ \left(\frac{1384*.0006}{.744^2*.106^2*.1}\right)^2$$

$$= 2500$$

MARGIN OF SAFTY

$$MS = \left(\frac{.85 * 47000}{22110 + 3 * 2500} \right) - 1$$

$$= .35$$

RELIABILITY

$$J = \frac{62,000 - 22110}{\sqrt{3900 + 2500}}$$

$$= 8.61$$

RELIABILITY = $.9_{11}$

ALLOCATION IS $.9_{10}88$

---------- RESULTS FOR 500 MONTE CARLO TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
STRS	0.2198E+05	0.2202E+05	2322.	0.3197E+05	0.1663E+05
DIFF	0.3802E+05	0.3766E+05	4897.	0.5121E+05	0.2601E+05

DO YOU WANT MORE MONTE CARLO TRIALS? NO

---------- RESULTS FOR VARIABLE STRS----------

	TABULAR HISTOGRAM				TEST FOR NORMAL	
VALUE	SIGMA	FREQ	CUM	CUM PROB	EXPECTED	DIFF.
16601.5596	-2.33	0	0	0.	0.009804	0.009804
19848.9941	-0.93	86	86	0.172000	0.174908	0.002908
23096.4285	0.46	271	357	0.714000	0.678631	0.035369
26343.8630	1.86	120	477	0.954000	0.968747	0.014747
29591.2976	3.26	21	498	0.996000	0.999446	0.003446
32838.7319	4.66	2	500	1.000000	0.999998	0.000002
HIGH END TAILS		0	500			

MAX DIFF. =0.035369

RELIABILITY ESTIMATED FROM SUCCESSES/POPULATION......R=1.0000000000
RELIABILITY ESTIMATED FROM LEAST SQUARES CURVE-FIT...R=1.0000000000
FROM THE 20 VALUES NEAREST ZERO, BELOW

0.260108E+05	0.263524E+05	0.264624E+05	0.265360E+05	0.266372E+05
0.267808E+05	0.268889E+05	0.269133E+05	0.270909E+05	0.273082E+05
0.274296E+05	0.274605E+05	0.274830E+05	0.275579E+05	0.278325E+05
0.280975E+05	0.290049E+05	0.290408E+05	0.290462E+05	0.290578E+05

CRITICAL DIFFERENCES (N GREATER THAN 50)	LEVEL OF SIGNIFICANCE				
	20%	15%	10%	5%	1%
	0.0479	0.0510	0.0546	0.0608	0.0729

PROGRAM STOP AT 496

USED 9.70 UNITS

BYE
0010.02 CRU 0000.27 TCH 0004.22 KC

OFF AT 13:25 L 06/29/71

```
          MONTE CARLO & SENSITIVITY ANALYSIS PROGRAM

IS THIS A MONTE CARLO OR SENSITIVITY ANALYSIS?
(ANSWER 'MONTE' OR 'SENS')?MONTE

DO YOU WANT TO USE STORED DATA FROM YOUR DATA-FILE?
(ANSWER 'YES' OR 'NO')?NO

NO. OF MONTE CARLO TRIALS & STARTING ODD INTEGER? 100  1297

NO. OF INPUT VARIABLES? 6


NO.,  TYPE?, A?, B?, C?
  1?  2  1384    18    0
  2?  2  .372    .0003 0
  3?  2  .744    .0006 0
  4?  2  .1      .01   0
  5?  2  .106    .006  0
  6?  2  6E4     4300  0


NO. OF CUMULATIVE PROBABILITY TABLES? 0


NO. OF OUTPUT VARIABLES & NO. OF VALUES TO BE RANKED? 2  20


'*' - ANS 'YES' OR 'NO'
'?' - ANS WITH APPROPIATE VALUE OR NAME
NO., NAME?, REL*, HISTO*, NO. INTERVALS?, LWR*, VALUE?, UPR*, VALUE?
  1?  STRS  NO    YES    5     NO   0   NO   0
  2?  DIFF  YES   NO     0     NO   0   NO   0


DO YOU WISH TO STORE YOUR INPUT DATA? YES
 FILE NAME, PLEASE? ACK



      ---------- RESULTS FOR    100 MONTE CARLO TRIALS ----------

VAR.        MEDIAN        MEAN          SIGMA    MAX VALUE     MIN VALUE
 STRS    0.2198E+05   0.2177E+05      2278.    0.3131E+05   0.1663E+05
 DIFF    0.3802E+05   0.3837E+05      4611.    0.5121E+05   0.2678E+05


DO YOU WANT MORE MONTE CARLO TRIALS?  YES
HOW MANY ADDITIONAL TRIALS (RESULTS ARE CUMULATIVE)? 400
```

```
NEW OR OLD--NEW
ENTER FILE NAME-CAP
READY


100 FUNCTION F(X,Y)
110 REAL X(100),Y(25)
120 P=X(1); R=X(2); B=X(3); T=X(4); H=X(5);  STRGTH=X(6)
130 Y(1)=0.35*P/((3.14159*R^2*B*T)/2+(B^2*H*T))
140 Y(2)=STRGTH-Y(1)
150 RETURN;END


SAVE
READY
COMPILW


CAP          13:13 L     06/29/71


 WARNING: MAIN             ROUTINE MISSING
 EXECUTION PERMITTED

         READY


USED     .12 UNITS
RENAME F
READY
REPLACE
READY


NEW
ENTER FILE NAME-ACK
READY
DSM
READY
         DATA FILE
X
READY
SAVE
READY
OLD ACK
READY
LIST


ACK          13:15 L     06/29/71

         DATA FILE


OLD MONTE*
READY
RUN
```

```
        MONTE CARLO & SENSITIVITY ANALYSIS PROGRAM

IS THIS A MONTE CARLO OR SENSITIVITY ANALYSIS?
(ANSWER 'MONTE' OR 'SENS')?SENS

DO YOU WANT TO USE STORED DATA FROM YOUR DATA FILE?
(ANSWER 'YES' OR 'NO')? NO

NO. OF INPUT VARIABLES? 6


NO., NAME?, NO. INCREMENTS?, NOMINAL?, LOW?, HIGH?
  1?  P      1      1384     18     0
  2?  R      1      .372     .0003  0
  3?  B      1      .744     .0006  0
  4?  T      1      .100     .01    0
  5?  H      1      .106     .006   0
  6?  STRGTH 1     6E6_4     4300   0


NO. OF OUTPUT VARIABLES TO BE ANALYZED? 1


WHICH VARIABLES?; NO.?, NAME?
? 1   Y1


DO YOU WISH TO STORE YOUR INPUT DATA? NO


        TABLE OF RESULTS OF SENSITIVITY ANALYSES

           (INPUT VARIABLE NO.  1, ' P    ')
```

'X'			'Y'	DY	DY/DX	[(DY/DX)SX]2
0.13300E+04	1	Y1	0.21121E+05			
0.13480E+04	1	Y1	0.21407E+05	0.28584E+03	0.15880E+02	0.81707E+05
0.13660E+04	1	Y1	0.21692E+05	0.28584E+03	0.15880E+02	0.81707E+05
0.13840E+04	1	Y1	0.21978E+05	0.28584E+03	0.15880E+02	0.81707E+05
0.14020E+04	1	Y1	0.22264E+05	0.28584E+03	0.15880E+02	0.81707E+05
0.14200E+04	1	Y1	0.22550E+05	0.28584E+03	0.15880E+02	0.81707E+05
0.14380E+04	1	Y1	0.22836E+05	0.28584E+03	0.15880E+02	0.81707E+05
OVERALL				-----------	-----------	-----------
SENSITIVITY	1	Y1		0.17151E+04	0.15880E+02	0.81707E+05

(INPUT VARIABLE NO. 2, ' R ')

'X'			'Y'	DY	DY/DX	[(DY/DX)SX]2
0.37110E+00	1	Y1	0.22056E+05			
0.37140E+00	1	Y1	0.22030E+05	-0.26113E+02	-0.87044E+05	0.68190E+03
0.37170E+00	1	Y1	0.22004E+05	-0.26073E+02	-0.86909E+05	0.67979E+03
0.37200E+00	1	Y1	0.21978E+05	-0.26032E+02	-0.86773E+05	0.67766E+03
0.37230E+00	1	Y1	0.21952E+05	-0.25991E+02	-0.86638E+05	0.67556E+03
0.37260E+00	1	Y1	0.21926E+05	-0.25951E+02	-0.86503E+05	0.67345E+03
0.37290E+00	1	Y1	0.21900E+05	-0.25910E+02	-0.86367E+05	0.67134E+03
OVERALL SENSITIVITY	1	Y1		-0.15607E+03	-0.86706E+05	0.67661E+03

(INPUT VARIABLE NO. 3, ' B ')

'X'			'Y'	DY	DY/DX	[(DY/DX)SX]2
0.74220E+00	1	Y1	0.22046E+05			
0.74280E+00	1	Y1	0.22023E+05	-0.22539E+02	-0.37565E+05	0.50800E+03
0.74340E+00	1	Y1	0.22001E+05	-0.22500E+02	-0.37501E+05	0.50627E+03
0.74400E+00	1	Y1	0.21978E+05	-0.22462E+02	-0.37437E+05	0.50455E+03
0.74460E+00	1	Y1	0.21956E+05	-0.22424E+02	-0.37373E+05	0.50283E+03
0.74520E+00	1	Y1	0.21933E+05	-0.22386E+02	-0.37310E+05	0.50113E+03
0.74580E+00	1	Y1	0.21911E+05	-0.22348E+02	-0.37246E+05	0.49942E+03
OVERALL SENSITIVITY	1	Y1		-0.13466E+03	-0.37405E+05	0.50370E+03

(INPUT VARIABLE NO. 4, ' T ')

'X'			'Y'	DY	DY/DX	[(DY/DX)SX]2
0.70000E-01	1	Y1	0.31397E+05			
0.80000E-01	1	Y1	0.27473E+05	-0.39247E+04	-0.39247E+06	0.15403E+08
0.90000E-01	1	Y1	0.24420E+05	-0.30525E+04	-0.30525E+06	0.93179E+07
0.10000E+00	1	Y1	0.21978E+05	-0.24420E+04	-0.24420E+06	0.59635E+07
0.11000E+00	1	Y1	0.19980E+05	-0.19980E+04	-0.19980E+06	0.39921E+07
0.12000E+00	1	Y1	0.18315E+05	-0.16650E+04	-0.16650E+06	0.27723E+07
0.13000E+00	1	Y1	0.16906E+05	-0.14089E+04	-0.14089E+06	0.19849E+07
OVERALL SENSITIVITY	1	Y1		-0.14491E+05	-0.24152E+06	0.58331E+07

(INPUT VARIABLE NO. 5, ' H ')

'X'		'Y'	DY	DY/DX	[(DY/DX)SX]2
0.88000E-01	1 Y1	0.23019E+05			
0.94000E-01	1 Y1	0.22661E+05	-0.35765E+03	-0.59608E+05	0.12791E+06
0.10000E+00	1 Y1	0.22314E+05	-0.34671E+03	-0.57784E+05	0.12021E+06
0.10600E+00	1 Y1	0.21978E+05	-0.33626E+03	-0.56043E+05	0.11307E+06
0.11200E+00	1 Y1	0.21652E+05	-0.32627E+03	-0.54379E+05	0.10645E+06
0.11800E+00	1 Y1	0.21335E+05	-0.31673E+03	-0.52788E+05	0.10032E+06
0.12400E+00	1 Y1	0.21028E+05	-0.30759E+03	-0.51266E+05	0.94615E+05
OVERALL SENSITIVITY	1 Y1		-0.19912E+04	-0.55311E+05	0.11014E+06

110141

(INPUT VARIABLE NO. 6, ' RGTH')

'X'		'Y'	DY	DY/DX	[(DY/DX)SX]2
0.47100E+05	1 Y1	0.21978E+05			
0.51400E+05	1 Y1	0.21978E+05	0.	0.	0.
0.55700E+05	1 Y1	0.21978E+05	0.	0.	0.
0.60000E+05	1 Y1	0.21978E+05	0.	0.	0.
0.64300E+05	1 Y1	0.21978E+05	0.	0.	0.
0.68600E+05	1 Y1	0.21978E+05	0.	0.	0.
0.72900E+05	1 Y1	0.21978E+05	0.	0.	0.
OVERALL SENSITIVITY	1 Y1		0.	0.	0.

6 MOST SIGNIFICANT INDEPENDENT VARIABLES RANKEDIN
ORDER OF DECREASING MAGNITUDE OF [(DY/DX)SX]**2

RESULTS FOR OUTPUT VARIABLE Y1

	INDEPENDENT VAR NO.	NAME	DY	DY/DX	[(DY/DX)SX]2
WELD THICK.	4	T	-0.14491E+05	-0.24152E+06	0.58331E+07
LEG HEIGHT	5	H	-0.19912E+04	-0.55311E+05	0.11014E+06
	1	P	0.17151E+04	0.15880E+02	0.81707E+05
	2	R	-0.15607E+03	-0.86706E+05	0.67661E+03
	3	B	-0.13466E+03	-0.37405E+05	0.50370E+03
	6	RGTH	0.	0.	0.

PROGRAM STOP AT 720

USED 1.60 UNITS

AGCS-0800-11

SUBJECT: JACKET RUPTURE FMA VII M	REPORT NO.	PAGE 14 OF
		DATE
		WORK ORDER
BY: R.D. Ackerman	CHK. BY	DATE 4-27-71

SUMMARY & CONCLUSION:

THERE ARE TWO CRITICAL AREAS IN THE JACKET WALL. ONE IS JUST BELOW THE FLANGE, AND THE OTHER IS AT THE AFT END. THIS ANALYSIS COVERS THE AFT END PROBLEM. THE OTHER SECTIN IS IN FMA VIII.

THE PRESENT DESIGN USING ARMCO 22-13-5 SHOWS MORE THAN ADEQUATE RELIABILITY THE LOADS ARE HIGH, HOWEVER ARMCO 22-13-5 HAS OUTSTANDING LOW TEMP PROPERTIES, AND NO STRUCTURAL PROBLEM WILL OCCUR IF ARMCO IS USED.

RELIABILITY IS $.9_{17}8$ ALLOCATION IS $.9_{10}$ FF

SUBJECT FMA VII M JACKET RUPTURE USING ARMCO 22-13-5 AFT END

BY R.L. Ackerman

CHK. BY

DATE 4-27-71

USE .075 THICK JACKET WALL AT AFT END. - DESIGN PER 1138000 SEC C-C STATION 20.

STRESS

$\bar{A}$ = 30,348 PSI FROM PG 2 OF THIS ANALYSIS.

D_A = 1374 PSI FROM PG 5

STRENGTH PER N4350:MM 70-448 DEC 70
ASSUME TEMP = -320°F, ACTUAL TEMP = -390°F

$\bar{S}$ = 117,000 PSI.

D_S = 7700 PSI. $(\bar{S} - .8\bar{S})/3$.

$\bar{B}_{YK}$ = 130,000 PSI.

DESIGN ALLOWABLE S = 94,000 PSI. $= .8 \times \bar{S}$

DESIGN ALLOWABLE B_{YK} = 100,000 PSI.

SUBJECT FMA VII M Armco Jacket

DATE

WORK ORDER

BY R.A. Ackerman

CHK. BY

DATE 9-27/71

MARGIN OF SAFTY

$$MS. = \frac{.85 * 100{,}000}{30{,}348 + 3 * 1374} - 1$$

$$\boxed{MS = +1.46}$$

RELIABILITY.

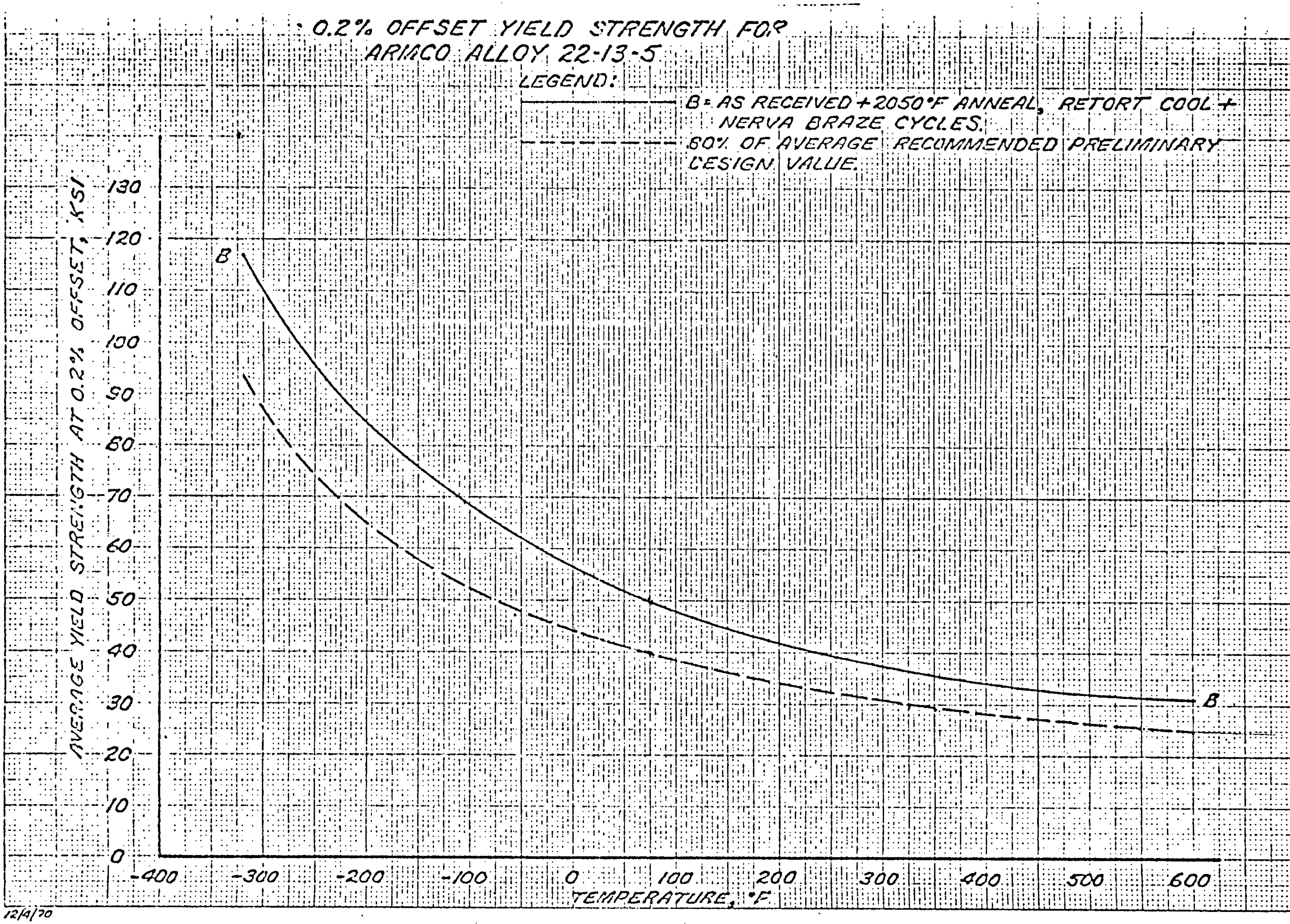
$$J = \frac{117{,}000 - 30{,}348}{\sqrt{7700^2 + 1374^2}} \doteq 11.1$$

$$\boxed{\text{RELIABILITY } \cancel{\doteq .9_{15}}}$$

$$= .9_{17}8$$

D

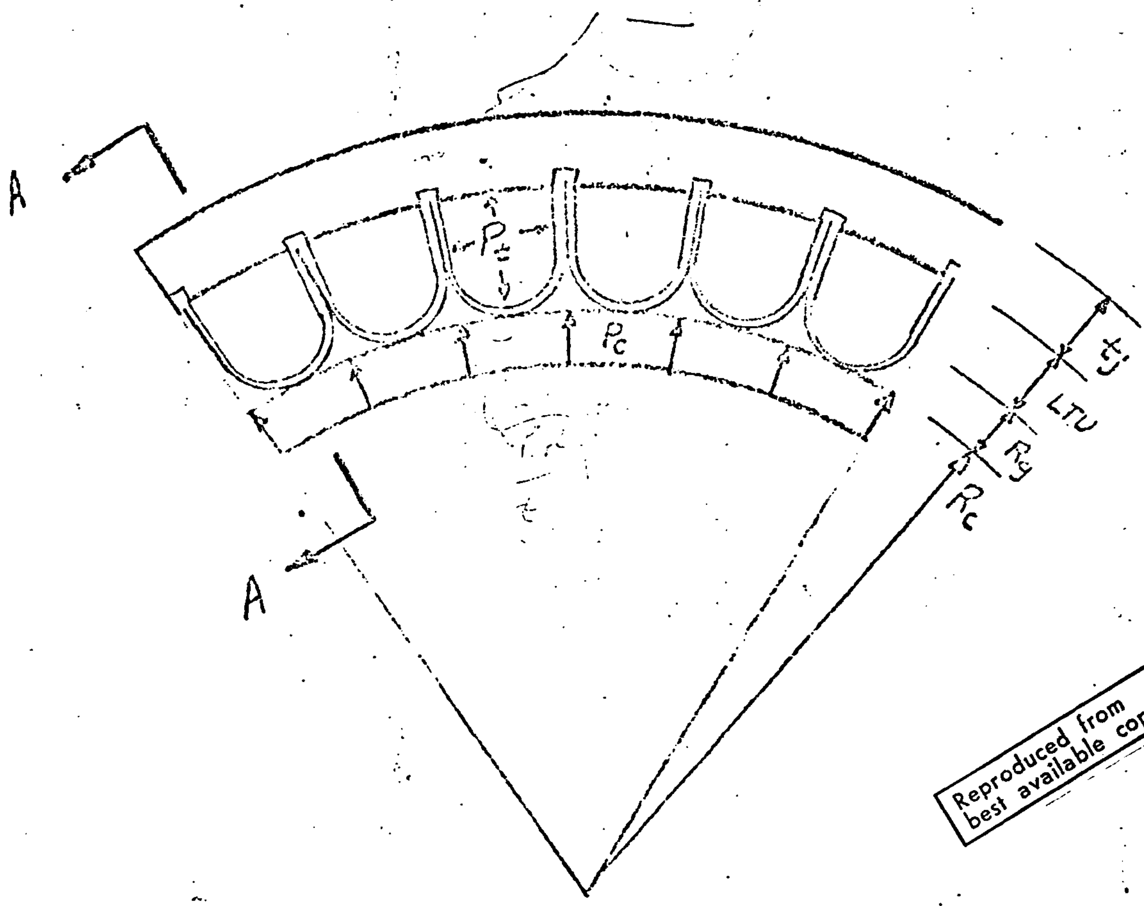
Fig 2


0.2% OFFSET YIELD STRENGTH FOR
ARMCO ALLOY 22-13-5
LEGEND:
B = AS RECEIVED + 2050°F ANNEAL, RETORT COOL + NERVA BRAZE CYCLES.
80% OF AVERAGE RECOMMENDED PRELIMINARY DESIGN VALUE.
AVERAGE YIELD STRENGTH AT 0.2% OFFSET, KSI
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-400
-300
-200
-100
0
100
200
300
400
500
600
TEMPERATURE, °F
B
B
12/4/70

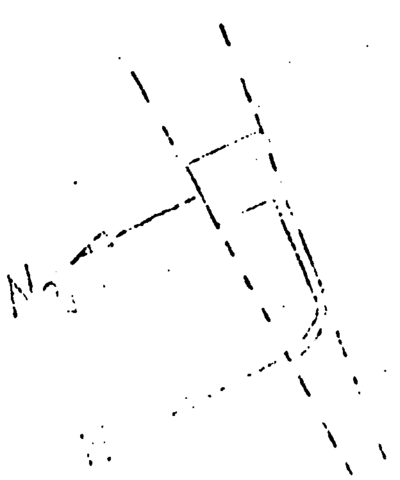
AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

AGCS 0800-11

	REPORT NO.	PAGE 4 OF
SUBJECT U-tube jacket thickness required for 1450 psi coolant pressure		DATE 2-11-73
		WORK ORDER
BY W DE LA GARZA	CHK. BY	DATE



at section A-A we have from static equilibrium



$$N_{\theta t} = P_t(R_g)$$

$$N_{\theta j\,avg} = P_c(R_c) + P_t(LTU)$$

$$\sigma_{\theta t} = \frac{P_t R_g}{t_t}$$

3

AEROJET-GENERAL CORPORATION
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AGCS-0800-11

SUBJECT	REPORT NO	PAGE 5 OF
		DATE 2-11-70
		WORK ORDER
BY W DE LA GARZA	CHK. BY	DATE

also

$$\sigma_j = \frac{N_{\theta j}}{t_j}$$

$$= \frac{P_c R_c + P_t LTU}{t_j \cos\alpha}$$

We have a bending moment (internal) at the seat of each tube

$$M_{\theta j} = \frac{P_t [2 R_j]^2}{12}$$

$$= \frac{P_t}{3} R_j^2$$

$$\sigma_{jMAX} = 2 \frac{P_t R_j^2}{t_j^2} \qquad \frac{6 M}{t^2} \leftarrow \frac{P_t}{3} R_q^2$$

Now, given an allowable stress of 30,000 psi (F_{ty}) we are limited to $0.85 F_{ty}$ for membrane and F_{ty} for membrane plus bending. So our design condition is

$$25,500 \geq \frac{P_c R_c + P_t LTU}{t_j \cos\alpha}$$

[illegible]

combining these we can rewrite them

$$25{,}500 \geq \frac{P_c R_c + P_t LTU}{t_j \cos\alpha}$$

$$4{,}500 \geq 2 P_t \left(\frac{R_g}{t_j}\right)^2$$

or

$$t_j \geq \frac{P_c R_c + P_t LTU}{25{,}500 \cos\alpha}$$

$$t_j^2 \geq \frac{2 P_t R_g^2}{4500}$$

which can be written

$$t_j^2 + t_j - \left[\frac{P_c R_c + P_t LTU}{25{,}500 \cos\alpha} + \frac{2 P_t R_g^2}{4500}\right] \geq 0$$

which has a solution

$$t_j \geq \frac{-1 + \sqrt{1 + 4\left[\frac{P_c R_c + P_t LTU}{25{,}500 \cos\alpha} + \frac{2 P_t R_g^2}{4500}\right]}}{2}$$

$t = .075$ $\quad$ $.085 \pm \cancel{.005}\ .010$

$t = .060$ $\quad$ $\cancel{.065} \pm$

$.070 \pm .015$

taking

$R_g = 0.181$ @ 5:1 $\pm .002$

$LTU = 0.734$ $\pm .002$

$P_t = 1450$ ± 25

$P_c = 20$ ± 2

$R_c = .12.45$ ± 010

$\cos\alpha = 0.866$ $\pm 2°$

we get

$t_j \geq 0.07796$

AGCS-0800-11

AEROJET-GENERAL CORPORATION
SACRAMENTO • CALIFORNIA

REPORT NO.

PAGE 1 OF

SUBJECT

FMA VII N. JACKET/TUBE BRAZE JOINT

DATE

WORK ORDER

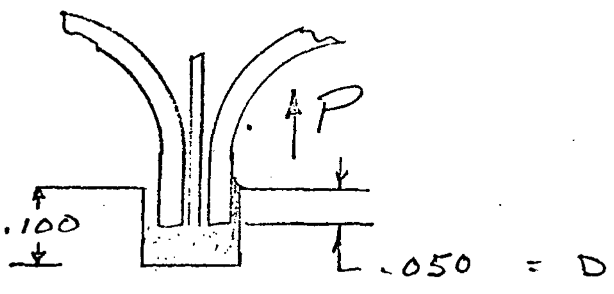
BY R.G. Ackerman

CHK. BY

DATE 3/12/71

REVISED 10/27/71

DETERMINE RELIABILITY OF NOZZLE TUBE TO JACKET BRAZE JOINT DUE TO SHEAR STRESS PRODUCED BY INTERNAL PRESSURE. CALCULATE AT COOLANT INLET.



* MATERIAL SHEAR STRENGTH, BASED ON BRAZE JOINT TESTS CONDUCTED DURING PHEOBUS PROGRAM. Ref PHEOBUS MATERIALS FINAL REPORT RP-SR-0002 SEPT 1967

$\bar{S}_s = 61{,}300$ PSI.

$D_s = 3600$ PSI.

* PLEASE SEE NOTE OF CAUTION Pg 6

AGCS-0800-11

	REPORT NO.	PAGE 2 OF
SUBJECT SECTION VII N CONTINUED		DATE
		WORK ORDER
BY RGA	CHK. BY	DATE 3/12/71

REVISED 10/29/71

SHEAR STRESS WILL BE BASED ON THE INTERNAL TUBE PRESSURE, THE CROSSSECTIONAL AREA OF THE TUBE, AND CROSS SECTION OF THE BRAZE JOINT.

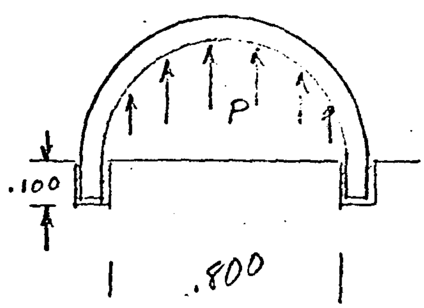
THE BRAZE JOINT AREA OF CONTACT WILL BE BASED ON 50 % OF THE TUBE LEG IN CONTACT WITH THE JACKET.

AT COOLANT INLET

INTERNAL TUBE PRESSURE $P = 1359$ $D_P = 18.6$

TUBE CROSS SECTION AREA $A_1 = .800 * 1 = .800\ IN^2$

BRAZED AREA $A_2 = .05 * 4 * 1 = .200\ IN^2$



NOTE: THE BRAZE AREA PER UNIT LENGTH CONSISTS OF A .050 STRIP ON EACH SIDE OF TWO LEGS ∴ 4 STRIPS.

$D_{A_2} = .020\ IN^2$

AGCS-0800-11

REPORT NO.	PAGE 3 OF

SUBJECT: VII N CONTINUED

DATE:

WORK ORDER:

BY: RGA | CHK. BY: | DATE: 3/12/71

Revised 10/29/71

FORCE ACTING ON TUBE IN 1 INCH OF LENGTH

$$F = P\left(\frac{Lb}{IN^2}\right) * A\,(IN^2)$$

$$= 1359 * .800$$

$$= 1087$$

$$\text{STRESS}(\sigma) = F/A \qquad A = 4\,D * 1 = .200$$

$$D = .050$$

$$\sigma = 1087 / .200$$

$$= 5436 \text{ PSI.}$$

$$D_\sigma^2 = \left(\frac{\partial\sigma}{\partial P} D_P\right)^2 + \left(\frac{\partial\sigma}{\partial L} D_L\right)^2 + \left(\frac{\partial\sigma}{\partial D} D_D\right)^2$$

$$= \left(\frac{D_P}{L*D}\right)^2 + \left(\frac{P\,D_L}{D*L^2}\right)^2 + \left(\frac{P\,D_D}{L*D^2}\right)^2$$

$$= \left(\frac{15.6}{.200}\right)^2 + \left(\frac{1359*.0033}{.200*1^2}\right)^2 + \left(\frac{1359*.003}{1*.2^2}\right)^2$$

$$= 99$$

REVISED 10/29/71

$$MS = \frac{.85 * (61{,}300 - 3 * 3600)}{5436 + 3 * 99} - 1$$

$$= 6.4$$

$$J = \frac{63{,}300 - 5436}{\sqrt{3600^2 + 99^2}} = 16.0$$

RELIABILITY >.915

AGCS-0800-11

SUBJECT Jacket / Tube Braze Joint FMA VII N.	REPORT NO.	PAGE 5 OF
		DATE
		WORK ORDER
BY R C Ackerman	CHK. BY	DATE 10/25/71

Determine Contact Area Required for .9₁₀ Reliability ($J = 8.15$)

$$\bar{\sigma} = \bar{S} - J\sqrt{D_S^2 + D_\sigma^2}$$

$$= 63{,}300 - 8.15\sqrt{3600^2 + 1675^2}$$

$$= 30{,}939$$

$$\bar{\sigma} = F/A$$

$$A = F/\bar{\sigma} = 1087/30939$$

$$= .035$$

A = Length * Depth

Length = 1

The .035 is the total Req'd for 2 legs, assume braze coverage on the inside of two legs, and total depth of insertion required is .035/2

Depth Req'd = .018 inches on each leg

CAUTION:

MATERIALS DATA USED FOR THIS ANALYSIS WAS GENERATED FOR THE PHOEBUS PROGRAM APPROX 4 YRS AGO, USING HASTELLOY X.

THE MEAN AND SIGMA WERE FOUND BY USING 17 SPECIMENS THAT WERE BRAZED WITH NIORO. ROOM TEMP SHEAR TEST RESULTS WERE USED. THE BRAZE JOINT OPERATES AT NEAR 70°R THEREFORE A HIGHER MEAN AND SIGMA COULD BE USED WHEN THE DATA BECOMES AVAILABLE. HOWEVER NO TESTS ARE PLANNED AT PRESENT.

IN ADDITION, THE BRAZE JOINT WILL BE A COMBINATION OF ALLOYS, AND THIS COULD CHANGE THE STRENGTH.

RUN

Section N page 7

```
SIGMA         13:31 L       05/13/71


TITLE?   NIOBO SHEAR STRENGTH-RT-.0002 PLATE

POPULATION SIZE & DATA?  6,68.0,60.2,60.1,57.4,59.5,62.6


MEAN  =  0.61300000E+02
SIGMA =  0.36791329E+01


TITLE?   NIOBO SHEAR STRENGTH -RT- .0005 PLATE

POPULATION SIZE & DATA?5,52.3,62.9,62.7,62.00_,63.8


MEAN  =  0.60740000E+02
SIGMA =  0.47616133E+01


TITLE?   NIOBO SHEAR STRENGTH -RT- .0008 PLATE

POPULATION SIZE & DATA?   6,63.0,66.1,59.5,57.9,59.1,65.4


MEAN  =  0.61833333E+02
SIGMA =  0.34834874E+01


TITLE?   NIOBO SHEAR STRENGTH -RT- .0002 THROUGH .0008 PLATE

POPULATION SIZE & DATA?   17,68.0.60.2,60.1,57.4,59.5,62.6,52.3

.-IS BAD CHAR IN DATA OR BAD FORMAT.

RETYPE DATA FOR LIST IN LINE 150
?17,68.0,66_0.2,60.1,57.4,59.5,62.6,52.3,62.9,62.7,62.0,63.8,63.0
?66.1,59.5,57.9,59.1,65.4


MEAN  =  0.61323529E+02
SIGMA =  0.37275237E+01


TITLE?   NIOBO SHEAR STRENGTH AT -320 DEGREES F

POPULATION SIZE & DATA?    4,78.9,82.8,82.7,82.1


MEAN  =  0.81625001E+02
SIGMA =  0.18427345E+01
```

THIS ANALYSIS WILL RECALCULATE INLET MANIFOLD WELD RELIABILITY USING LATER TEMPERATURE CALCULATIONS CONDUCTED ON THE NOZZLE/EXTENSION JOINT.

THE VALUE FOR HOOP + BENDING STRESS USED IN THE PREVIOUS ANALYSIS DTD 6/17/71 WILL BE USED IN THIS ANALYSIS, ALONG WITH THE PREVIOUSLY CALCULATED STRESS VARIATION.

MATERIAL TEMPERATURE. (LOWER WELD) ARMCO 22-13-

$T = -312\,^{\circ}F.$ REF N8110:M1710 18 JUNE 1971

SEE GRAPH ON FOLLOWING PAGE.

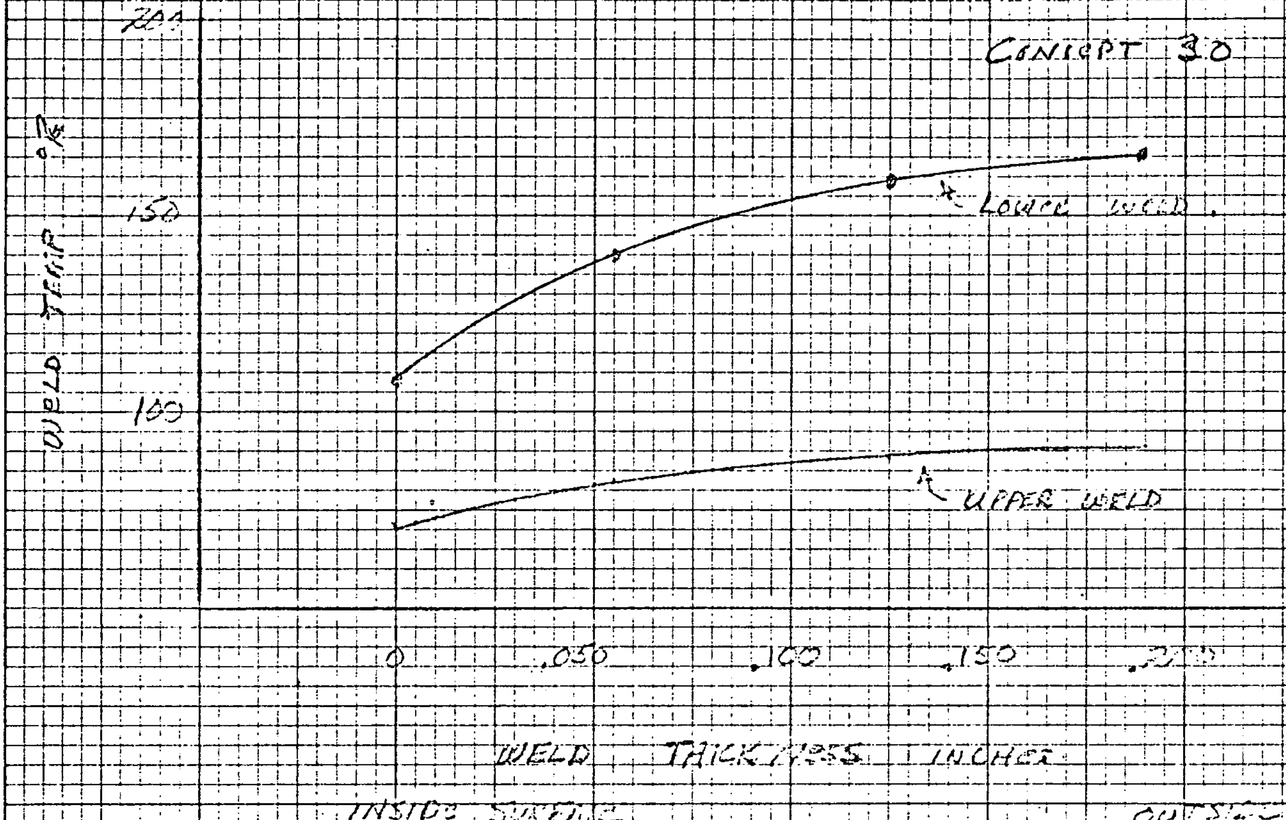
$\bar{S} = 110\,000$ PSI. REF N9350: MM 70-448

$D_S = 7260$ PSI.

$S_{Des} = 88,000$ PSI.

TEMPERATURE ACROSS INLET TORUS
TO JACKET WELD

Ref N 8110 : M 1710
18 June 1971
J J WILLIAMS
CONCEPT 3.0

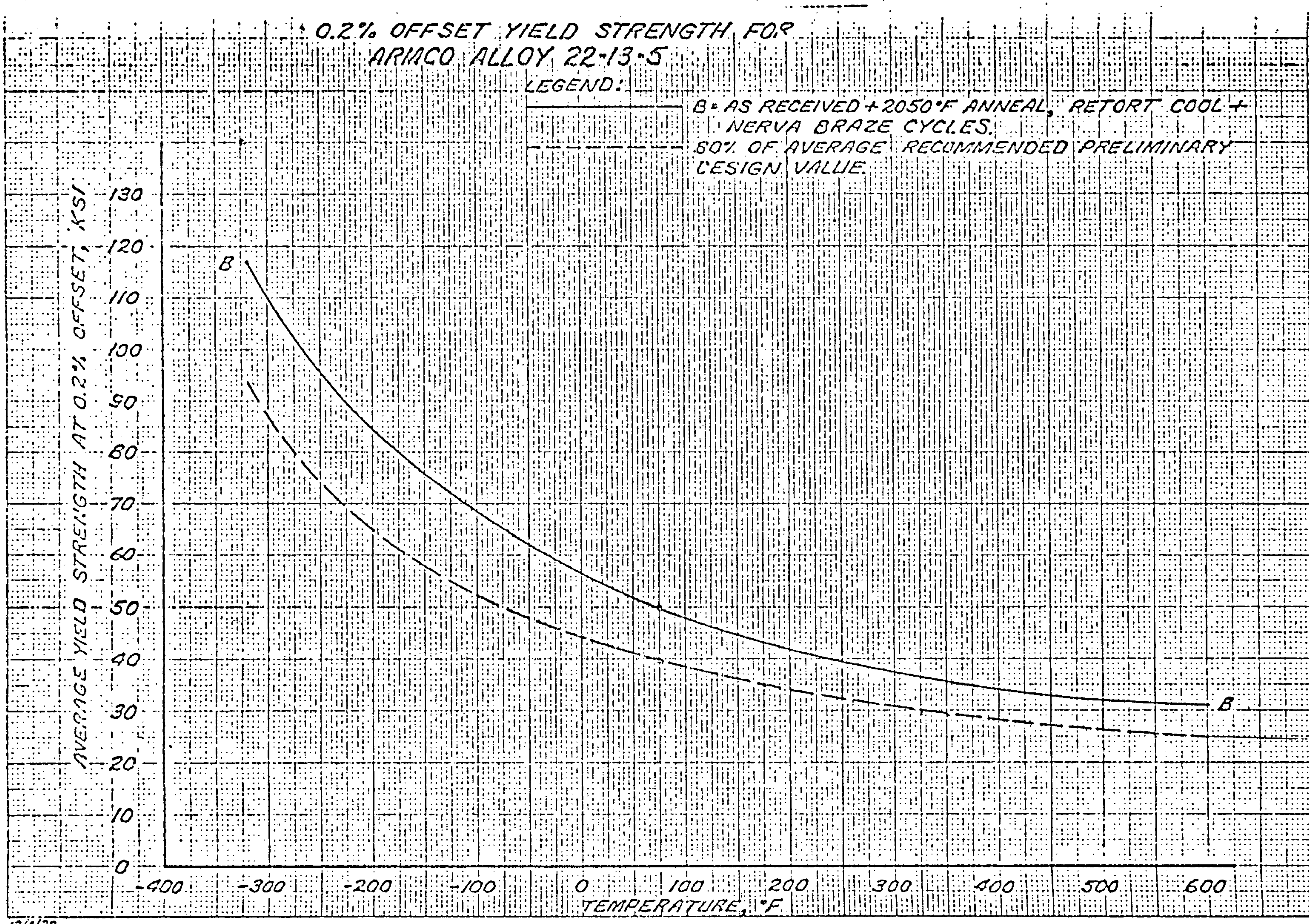


$$T = \frac{.050}{3 * .200}\left(108 + 4 * 137 + 2 * 155 + 4 * 161 + 166\right)$$

$$= 147\ ^\circ C$$

$$= 312\ ^\circ F$$

Fig 2



SECTION IC

AGCS-0800-11	REPORT NO.	PAGE 3 OF
SUBJECT: SECTION O CONTINUED		DATE
		WORK ORDER
BY: RGA	CHK. BY	DATE 1/4/72

THE LOAD IS A COMBINATION OF BENDING PLUS TENSION THEREFORE THE STRENGTH MUST BE INCREASED PER SNPO-C-1 APPENDIX I

AT THIS HIGH VALUE OF STRENGTH, FIG II-2 MUST BE USED

$\overline{B}_{YK}$ = 120,000 PSI.

B_{YK} DESIGN ALLOWABLE = 100,000 PSI.

D_{BYK} = 7260 PSI.

STRESS PER 6/17/71 ANALYSIS

BENDING STRESS $\bar{\sigma}_B$ = 26,600 PSI.

HOOP TENSION STRESS $\bar{\sigma}_H$ = 17390

TOTAL STRESS $\bar{\sigma}$ = 43,990 PSI.

STRESS VARIATION FROM 6/17/71 ANALYSIS.

BENDING $D_{\Delta B} = 616$ PSI.

HOOP $D_{\Delta H} = 430$

TOTAL $D_\Delta = 1046$ PSI.

STRESS MAX $= \bar{\Delta} + 3\ D_\Delta$

$= 43990 + 3 * 1046$

$= 47128$

MARGIN OF SAFTY

$$MS = \frac{.85 * 100{,}000}{47128} - 1$$

$= .80$

RELIABILITY

$$J = \frac{120{,}000 - 43990}{\sqrt{7260^2 + 1096^2}}$$

$$= 10.36$$

RELIABILITY = .9$_{15}$71   FOR N = 20
90 % CONFIDENCE.

THE RELIABILITY OF THE INLET MANIFOLD AND MANIFOLD IS VERY HIGH, AND MAY HAVE POTENTIAL FOR WEIGHT REDUCTION.

RECOMMEND REDESIGN WHEN NEW MATERIALS DATA IS AVAILABLE.

Section O

11:28PST 01/04/72

TOLERANCE FACTOR................?10.62

EQUIVALENT DEGREES OF FREEDOM..? 19

SAMPLE SIZE FOR MEAN...........? 20

CONFIDENCE LEVEL...............? 0.90

RESULTS------

1 - RELIABILITY = 0.53275379E-16

INVERSE OF NORM. CUM. DIST. FUNCTION = 8.29724801

9,16 47

PROGRAM STOP AT 350

USED 2.95 UNITS

RUN

INLET MANIFOLD

11:30PST 01/04/72

TOLERANCE FACTOR................? 10.36

EQUIVALENT DEGREES OF FREEDOM..? 19

SAMPLE SIZE FOR MEAN...........? 20

CONFIDENCE LEVEL...............? 0.90

RESULTS------

1 - RELIABILITY = 0.29065546E-15

INVERSE OF NORM. CUM. DIST. FUNCTION = 8.09317112

@

READY

9,15 71

INLET MANIFILD

LOWER WELD.

DETERMINE STRESS IN BOLT COOLANT MANIFOLD DUE TO BENDING CAUSED BY INTERNAL PRESSURE. USE MODEL DEVELOPED FOR FMA VIII O

SEE PAGES 1 – 4 OF FMA VII O FOR EQUATION DERIVATION.

FROM Pg 4. BENDING STRESS =

$$\bar{s}_B = \frac{.908\, \beta\, (2-\nu)\, r}{\tau}$$

$$D^2_{S_B} = \left(\frac{\partial s}{\partial \beta} D_\beta\right)^2 + \left(\frac{\partial s}{\partial \nu} D_\nu\right)^2 + \left(\frac{\partial s}{\partial r} D_r\right)^2 + \left(\frac{\partial s}{\partial \tau} D_\tau\right.$$

$$= \left(\frac{.908 * (2-\nu) * r * D_\beta}{\tau}\right)^2 + \left(\frac{.908 * r * \beta * D_\nu}{\tau}\right)^2$$

$$+ \left(\frac{.908 * \beta * (2-\nu) * D_r}{\tau}\right)^2 + \left(\frac{.908 * \beta * (2-\nu) * r * D_\tau}{\tau^2}\right.$$

SUBJECT

Section Q Continued

DATE

WORK ORDER

BY

CHK. BY

DATE

Parameters.

$\beta = 1261$ Psi. $\qquad D_p = 18$

$\nu = .29$ $\qquad D_\nu = .01$

$r = .83$ $\qquad D_r = .005$

$t = .140$ $\qquad D_t = .0033$

$$\bar{s}_B = \frac{.908 * 1261 * (2-.29) * .83}{.140}$$

$$= 11{,}607$$

$$D_s^2 = \left(\frac{.908 * 1.71 * .83 * 18}{.140}\right)^2 + \left(\frac{.908 * .83 * 1261 * .01}{.140}\right)^2$$

$$+ \left(\frac{.908 * 1261 * 1.71 * .005}{.140}\right)^2 + \left(\frac{.908 * 1261 * 1.71 * .83 * .0033}{.140^2}\right)$$

$$D_s = 334$$

MATERIAL PROPERTIES

PER ARMCO SCREENING PROGRAM

MEMO 4350: MM 70 - 448 22 DEC 70

MEAN WALL TEMP = $-300°F$

ESTIMATED FROM MEMO 7731: M1487 DTD

10 JULY 1970. - FOR 2.5 INCH FLANGE.

MEAN STRENGTH $\bar{S} = 110{,}000$ PSI.

DESIGN ALLOW $S_{DES} = 86{,}000$ PSI.

VARIABILITY $D_S = 8{,}000$ PSI.

FOR BENDING PLUS HOOP STRESS

$\bar{B}_{YK} = 125{,}000$

$B_{YK\,DES} = 95{,}000$ PSI.

HOOP STRESS FROM FMA VII H.

$$\bar{\sigma}_H = 6655 \text{ PSI.}$$

$$D_\sigma = 162 \text{ PSI.}$$

HOOP + BENDING STRESS σ_T

$$\sigma_T = \bar{\sigma}_B + \bar{\sigma}_H = 11607 + 6655$$
$$= 18{,}262 \text{ PSI}$$

$$D_{\sigma_T} = D_{\sigma_H} + D_{\sigma_B} = 162 + 334$$
$$= 496$$

M.S. FOR HOOP + BENDING

$$M.S. = \frac{.85\ B_{1K\,DES}}{\bar{\sigma}_T + 3\ D_\sigma}$$

$$= \frac{.85 * 95000}{18{,}262 + 3 * 496}$$

$$M.S. = +3.08$$

RELIABILITY.

$$J = \frac{\bar{B}_{YK} - \bar{A}_{T}}{\sqrt{D_S^2 + D_a^2}} = \frac{125{,}000 - 18{,}262}{\sqrt{8000^2 + 4916^2}}$$

$$= 13.3$$

BOLT BENDING + COOLANT MANIFOLD HOOP. STRESS FMA VII Q

---------- RESULTS FOR 500 MONTE CARLO TRIALS ----------

VAR.	MEDIAN	MEAN	SIGMA	MAX VALUE	MIN VALUE
BEND	0.1161E+05	0.1165E+05	359.6	0.1294E+05	0.1073E+05
HOOP	7476.	7502.	222.1	8309.	6895.
TOTL	0.1908E+05	0.1915E+05	579.2	0.2125E+05	0.1766E+05
DIFF	0.1059E+06	0.1058E+06	8153.	0.1294E+06	0.8442E+05

DO YOU WANT MORE MONTE CARLO TRIALS? NO

---------- RESULTS FOR VARIABLE BEND----------

	TABULAR HISTOGRAM				TEST FOR NORMAL	
VALUE	SIGMA	FREQ	CUM	CUM PROB	EXPECTED	DIFF.
10606.9784	-2.89	0	0	0.	0.001909	0.001909
11028.3884	-1.72	13	13	0.026000	0.042649	0.016649
11449.7986	-0.55	133	146	0.292000	0.291596	0.000404
11871.2086	0.62	229	375	0.750000	0.733452	0.016548
12292.6188	1.80	102	477	0.954000	0.963697	0.009697
12714.0288	2.97	21	498	0.996000	0.998498	0.002498
HIGH END TAILS		2	500			

MAX DIFF. =0.016649

---------- RESULTS FOR VARIABLE HOOP----------

	TABULAR HISTOGRAM				TEST FOR NORMAL	
VALUE	SIGMA	FREQ	CUM	CUM PROB	EXPECTED	DIFF.
6865.1436	-2.87	0	0	0.	0.002076	0.002076
7298.4358	-0.92	88	88	0.176000	0.179869	0.003869
7731.7280	1.03	335	423	0.846000	0.849575	0.003575
8165.0202	2.99	74	497	0.994000	0.998583	0.004583
HIGH END TAILS		3	500			

MAX DIFF. =0.004583

R is > .9/10

RELIABILITY ESTIMATED FROM SUCCESSES/POPULATION......R=1.0000000000
RELIABILITY ESTIMATED FROM LEAST SQUARES CURVE-FIT...R=1.0000000000
FROM THE 20 VALUES NEAREST ZERO, BELOW

0.844240E+05	0.856337E+05	0.864824E+05	0.867795E+05	0.868227E+05
0.881372E+05	0.882794E+05	0.885094E+05	0.886711E+05	0.893282E+05
0.895963E+05	0.899903E+05	0.900689E+05	0.907192E+05	0.911105E+05
0.913679E+05	0.914765E+05	0.915075E+05	0.916445E+05	0.916672E+05

CRITICAL DIFFERENCES (N GREATER THAN 50)	LEVEL OF SIGNIFICANCE				
	20%	15%	10%	5%	1%
	0.0479	0.0510	0.0546	0.0608	0.0729

PROGRAM STOP AT 496

USED 10.29 UNITS

```
LIST
```

BOLT COOLANT MANIFOLD ANALYSIS.
FMA VII Φ

```
COOL          10:48 L      06/22/71

100 FUNCTION F(X,Y)
110 REAL X(100),Y(25)
120 P=X(1);V=X(2);R=X(3);T=X(4); STRGTH=X(5)
130 Y(1)=(.908*P*(2-V)*R)/T
140 Y(2)=P*R/T
150 Y(3)=Y(1)+Y(2)
160 Y(4)=STRGTH-Y(3)
170 RETURN;END


READY
UNSAVE
READY



OLD ACK
READY
LIST


ACK           10:49 L      06/22/71

        100         1297           5             0          4            20
          1            2   1.2610000E+03  1.8000000E+01    0.
          2            2   2.9000000E-01  1.0000000E-02    0.
          3            2   8.3000000E-01  5.0000000E-03    0.
          4            2   1.4000000E-01  3.3000000E-03    0.
          5            2   1.2500000E+05  8.0000000E+03    0.
   1   BEND   NO     YES     5  NO     0.                  NO    0.
   2   HOOP   NO     YES     3  NO     0.                  NO    0.
   3   TOTL   NO     NO      0  NO     0.                  NO    0.
   4   DIFF   YES    NO      0  NO     0.                  NO    0.
```

7

```
READY
```